



64/1462/NP

NEW WORK ITEM PROPOSAL

Proposer TC 64/Secretariat	Date of proposal 2005-05-04
TC/SC TC 64	Secretariat Germany
Date of circulation 2005-05-13	Closing date for voting 2005-09-02

A proposal for a new work item within the scope of an existing technical committee or subcommittee shall be submitted to the Central Office. The proposal will be distributed to the P-members of the technical committee or subcommittee for voting, and to the O-members for information. The proposer may be a National Committee of the IEC, the secretariat itself, another technical committee or subcommittee, an organization in liaison, the Standardization Management Board or one of the advisory committees, or the General Secretary. Guidelines for proposing and justifying a new work item are given in ISO/IEC Directives, Part 1, Annex C (see extract overleaf). **This form is not to be used for amendments or revisions to existing publications.**

The proposal (to be completed by the proposer)

Title of proposal IEC 61201 : Touch voltage threshold values for protection against electric shock		
<input type="checkbox"/> Standard	<input checked="" type="checkbox"/> Technical Specification	<input type="checkbox"/> Publicly Available Specification
Scope (as defined in ISO/IEC Directives, Part 2, 6.2.1) See enclosed draft		
Purpose and justification , including the market relevance and relationship to Safety (Guide 104), EMC (Guide 107), Environmental aspects (Guide 109) and Quality assurance (Guide 102) . (attach a separate page as annex, if necessary) See "introduction" of the enclosed draft Attention is drawn to the fact that this document is proposed to be published as a Technical Specification and as a "Basic Safety Publication".		
Target date	for first CD June 2005	for IS 2008
Estimated number of meetings	Frequency of meetings: per year	Date and place of first meeting:
Proposed working methods	<input type="checkbox"/> E-mail	<input type="checkbox"/> ftp
Relevant documents to be considered		
Relationship of project to activities of other international bodies		
Liaison organizations	Need for coordination within ISO or IEC	
Preparatory work Ensure that all copyright issues are identified. Check one of the two following boxes <input checked="" type="checkbox"/> A draft is attached for vote and comment <input type="checkbox"/> An outline is attached		
We nominate a project leader as follows in accordance with ISO/IEC Directives, Part 1, 2.3.4 (name, address, fax and e-mail): Mr. Etienne TISON - SCHNEIDER ELECTRIC 38TEC/T2 - FR-38000 Grenoble - France Tel: +33 (0)4 76 39 84 07 - Mob: +33 (0)6 87 75 07 95 - Fax: +33 (0)4 76 60 53 07 e-mail: etienne.tison@schneider-electric.com		
Concerns known patented items (see ISO/IEC Directives, Part 2) <input type="checkbox"/> yes If yes, provide full information as an annex <input checked="" type="checkbox"/> no		Name and/or signature of the proposer R. PELTA / TC64 Secretary

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Comments and recommendations from the TC/SC officers		
1) Work allocation <input checked="" type="checkbox"/> Project team <input type="checkbox"/> New working group <input type="checkbox"/> Existing working group no:		
2) Draft suitable for direct submission as <input checked="" type="checkbox"/> CD <input type="checkbox"/> CDV <input type="checkbox"/> Publication as a PAS		
3) General quality of the draft (conformity to ISO/IEC Directives, Part 2) <input type="checkbox"/> Little redrafting needed <input type="checkbox"/> Substantial redrafting needed <input type="checkbox"/> no draft (outline only)		
4) Relationship with other activities In IEC This document may be of interest of the following Technical Committees: TC2-TC7-TC8-TC9-TC11-TC13-TC14-TC17-TC18-TC20-TC21-TC22-TC23-TC26-TC27-TC28-TC29-TC31-TC32-TC33-TC34-TC35-TC36-TC37-TC38-TC39-TC40-TC42-TC44-TC45-TC46-TC47-TC48-TC49-TC55-TC57-TC59-TC61-TC62-TC65-TC66-TC69-TC71-TC72-TC76-TC78-TC79-TC80-TC81-TC82-TC85-TC87-TC88-TC90-TC91-TC93-TC94-TC95-TC96-TC97-TC98-TC99-TC100-TC103-TC104-TC106-TC107-TC108-TC109-TC110 and their respective sub-committees In other organizations		
Remarks from the TC/SC officers The proposal consists of the revision of the existing publication IEC 61201TR : Extra-low voltage (ELV) – Limit values (1 st edition). The proposal is based on the basic safety publication IEC 60479-1 : Effects of current on human beings and livestock – Part 1: General aspects Different environmental conditions have been considered in this document corresponding to those used in IEC 60479-1: - dry, waterwet and saltwater wet condition - large, medium and small contact areas The immersed and special condition are not covered by this new proposal IEC 61201 was initially under the responsibility of ACOS. The ACOS WGELV has been in charge of the elaboration of this proposal. ACOS recommended that IEC 61201 be transferred to TC 64. This recommendation was approved by the SMB. It is now the responsibility of TC 64 to complete the revision and convert the TR into a TS with the designation of a Basic Safety Publication.		

Elements to be clarified when proposing a new work item

Title

Indicate the subject matter of the proposed new standard.

Indicate whether it is intended to prepare a standard, a technical report or an amendment to an existing standard.

Scope

Give a clear indication of the coverage of the proposed new work item and, if necessary for clarity, exclusions.

Indicate whether the subject proposed relates to one or more of the fields of safety, EMC, the environment or quality assurance.

Purpose and justification

Give details based on a critical study of the following elements wherever practicable.

- The specific aims and reason for the standardization activity, with particular emphasis on the aspects of standardization to be covered, the problems it is expected to solve or the difficulties it is intended to overcome.
- The main interests that might benefit from or be affected by the activity, such as industry, consumers, trade, governments, distributors.
- Feasibility of the activity: Are there factors that could hinder the successful establishment or general application of the standard?
- Timeliness of the standard to be produced: Is the technology reasonably stabilized? If not, how much time is likely to be available before advances in technology may render the proposed standard outdated? Is the proposed standard required as a basis for the future development of the technology in question?
- Urgency of the activity, considering the needs of the market (industry, consumers, trade, governments etc.) as well as other fields or organizations. Indicate target date and, when a series of standards is proposed, suggest priorities.
- The benefits to be gained by the implementation of the proposed standard; alternatively, the loss or disadvantage(s) if no standard is established within a reasonable time. Data such as product volume or value of trade should be included and quantified.
- If the standardization activity is, or is likely to be, the subject of regulations or to require the harmonization of existing regulations, this should be indicated.

If a series of new work items is proposed, the purpose and justification of which is common, a common proposal may be drafted including all elements to be clarified and enumerating the titles and scopes of each individual item.

Relevant documents

List any known relevant documents (such as standards and regulations), regardless of their source. When the proposer considers that an existing well-established document may be acceptable as a standard (with or without amendments), indicate this with appropriate justification and attach a copy to the proposal.

Cooperation and liaison

List relevant organizations or bodies with which cooperation and liaison should exist.

Preparatory work

Indicate the name of the project leader nominated by the proposer.

INTERNATIONAL ELECTROTECHNICAL COMMISSION

Second Edition of IEC 61201

Touch voltage threshold values for protection against electric shock

INTRODUCTION

This Technical Specification replaces the first edition of IEC 61201 TR and provides voltage thresholds which are intended to give guidance to IEC technical committees on the selection and application of voltage limits with regard to protection against electric shock. Its purpose is to facilitate harmonization and consistency among different IEC publications. Technical Committees may use these voltage thresholds to set voltage limits in their product standards using appropriate risk factors.

To estimate the type and severity of physiological effects that might be caused by electricity, the magnitude and pathway of current through a person's body must be determined. However, from an equipment design point of view, it is advantageous to be able to predict whether unwanted physiological effects are possible or probable given only information about voltage levels on accessible conductive surfaces. If the maximum available voltage is sufficiently low under the expected circumstances to be unable to cause enough body current to cause unwanted physiological effects, then the safeguards normally required to avoid the occurrence of these physiological effects may be reduced or eliminated. Voltages below critical levels that are unlikely to be hazardous in this respect have normally been called Extra-Low Voltage (ELV). Based on this information Technical Committees may wish to review their defined values of Extra-Low Voltage. The objective of this document is to derive touch voltage threshold values corresponding to the zones of physiological effects presented in Figures 20 and 22 of document IEC 60479-1 (5th edition). The introduction of these techniques gives designers the ability to provide a larger variety of circuits giving the expected level of user protection under a broader set of circumstances than previously considered.

The physiological effects corresponding to the threshold voltage values should correspond to those for body current that appear in IEC 60479-1. Physiological effects considered in this report are ventricular fibrillation and effects involving muscular contractions such as inability to let go. Current thresholds are based on curves c_1 and b in IEC 60479-1. The touch voltage thresholds are related to the touch current thresholds by the body impedance according to Ohm's Law. However, in this case, the application of Ohm's Law is not straightforward. Body impedance is a function of a number of variables including the voltage across the body, the area of contact between the skin and the conductive surface, the level of moisture in the contact area, and the duration of voltage across (or current through) the body. When voltage is applied to the body and current begins to flow, the resistive component of the skin impedance changes to a lower value within a few tens of milliseconds.

This document discusses 50/60Hz sinusoidal alternating voltage and pure direct voltage having no significant alternating component. Higher frequency alternating voltage is not included in this type of analysis, as this would require a more complex body impedance model and would require the use of frequency factors for the current thresholds for the unwanted physiological effects. As this technical report does not cover higher frequencies than 50/60Hz, technical committees are requested to inform ACOS about experience gained on this subject. Suggestions for modifications and additions to the report should be submitted to ACOS.

This work does not relieve the responsibility to consider the usual touch current commonly measured in product evaluations.

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TOUCH VOLTAGE THRESHOLD VALUES FOR PROTECTION AGAINST ELECTRIC SHOCK

1. Scope

This Technical Specification provides guidance for the determination of the maximum permissible voltage levels between accessible conductive parts in various environmental situations. The maximum permissible voltage levels are determined for the specific environmental conditions involved based on the body impedance for particular current pathways likely for people in contact with the equipment or with the electrical source.

This specification considers only 50/60 Hz sinusoidal alternating voltage having no other frequency components and no significant direct voltage component, or direct voltage with no significant alternating component.

Other voltage waveforms are not covered here and would have to be the subject of a separate analysis.

This basic safety publication is primarily intended for use by technical committees in the preparation of standards in accordance with the principles laid down in IEC guide 104 and ISO/IEC guide 51. It is not intended for use by manufacturers or certification bodies.

One of the responsibilities of a technical committee is, wherever applicable, to make use of basic safety publications in the preparation of its publications. The requirements, test methods or test conditions of this basic safety publication will not apply unless specifically referred to or included in the relevant publications.

2. Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC guide 51:	Safety aspects - Guidelines for their inclusion in standards
IEC guide 104:	The preparation of safety publications and the use of basic safety publications and group safety publications
IEV 60050-195:	International Electrotechnical Vocabulary – Earthing and protection against electric shock
IEC 60479-1:	5 th ed. Effects of current passing through the human body. Part 1: General aspects. Chapter 1: Electrical impedance of the human body. Chapter 2: Effects of alternating current in the range of 15 Hz to 100 Hz. Chapter 3: Effects of direct current.
IEC 60990:	Method of measurement of touch current and protective conductor current

3. Definitions

3.1. Touch current

is the electric current passing through a human body or through an animal body when it touches one or more accessible parts of an installation or of equipment [IEV-195-05-21].

3.2. Touch voltage

is the voltage between conductive parts when touched simultaneously by a person or an animal [IEV 195-05-11].

NOTE - The touch voltage may be different from the open circuit voltage between those conductive parts.

3.3. Threshold

is a point at which a stimulus is just strong enough to produce a response.

NOTE – A threshold is not the same as a limit which must include risk assessment, safety margins, etc.

3.3.1. Voltage threshold for muscular reaction:

Minimum derived value of touch voltage for the population for which a current flowing through the body is just enough to cause involuntary contraction of a muscle, not including startle reaction, such as inability of let go from an electrode.

3.3.2. Voltage threshold for ventricular fibrillation:

Minimum derived value of touch voltage for the population for which a current flowing through the body is just enough to cause ventricular fibrillation.

4. Conditions and thresholds values

Physiological effects of electricity through the human body are caused by current through the body. In order to estimate the type and severity of physiological effects that might be caused by electricity, the magnitude and pathway of current through a person's body must be determined. However, from an equipment design point of view, it is advantageous to be able to predict whether unwanted physiological effects are possible or probable given only information about voltage levels on accessible conductive surfaces. If the maximum available voltage is sufficiently low to be unable to cause enough body current to cause unwanted physiological effects, then the safeguards normally required to avoid the occurrence of these physiological effects may be reduced or eliminated.

NOTE – This document only estimates the touch voltage and not the effect of the source impedance. This results in the worst case situation. This means that the prospective touch voltage is equal to the effective touch voltage as defined in IEC 50060-195.

4.1. Physiological effects of body current

Thresholds for the physiological effects associated with electric current through a human body are reported in IEC 60479-1.

Figures 1 to 3 below show the thresholds for body current on which the voltage thresholds are based. These figures are based only on information from IEC 60479-1 (5th edition). Figures 1; 2 and 3 respectively show the threshold current values for hand-to-hand; hands-to-feet or hand-to-seat (longitudinal) current.

Figure 2 directly reproduces Figures 20 and 22 of IEC 60479-1 (5th edition). Other Figures are derived from IEC 60479-1 using the appropriate factors of table 5 to adapt the threshold current to the hand-to-hand pathway.

For the purposes of this report, the threshold of physiological effects of greatest interest are curves b and c₁. Curve b is the lower boundary of current levels beyond which more serious and undesirable physiological effects begin to occur. These more serious effects include muscular effects such as inability to let go. Curve c₁ is the level beyond which the likelihood of ventricular fibrillation begins to become a concern.

The values in Table 1 refer to long duration current through the torso. For a.c. the main concern is the inability to let-go which refers to the current through each arm. Therefore the a.c. current value in Table 1 and in Figure 2 is doubled for both hands to both feet pathway for longer current duration. For d.c. and for shorter ac duration the value is not doubled because continuous d.c. and short duration ac current do not cause inability to let-go.

For direct current, a lower magnitude of current is needed to produce ventricular fibrillation when the current flows upward from feet to hands (feet positive with respect to the upper body) through the torso rather than downward. This report assumes upward current in all cases involving direct current. The ventricular fibrillation current threshold for a d.c. downwards current is about twice that of the current threshold corresponding to the upward current.

Short duration currents (less than one heart cycle) are always assumed to coincide with the vulnerable portion of the heart beat cycle.

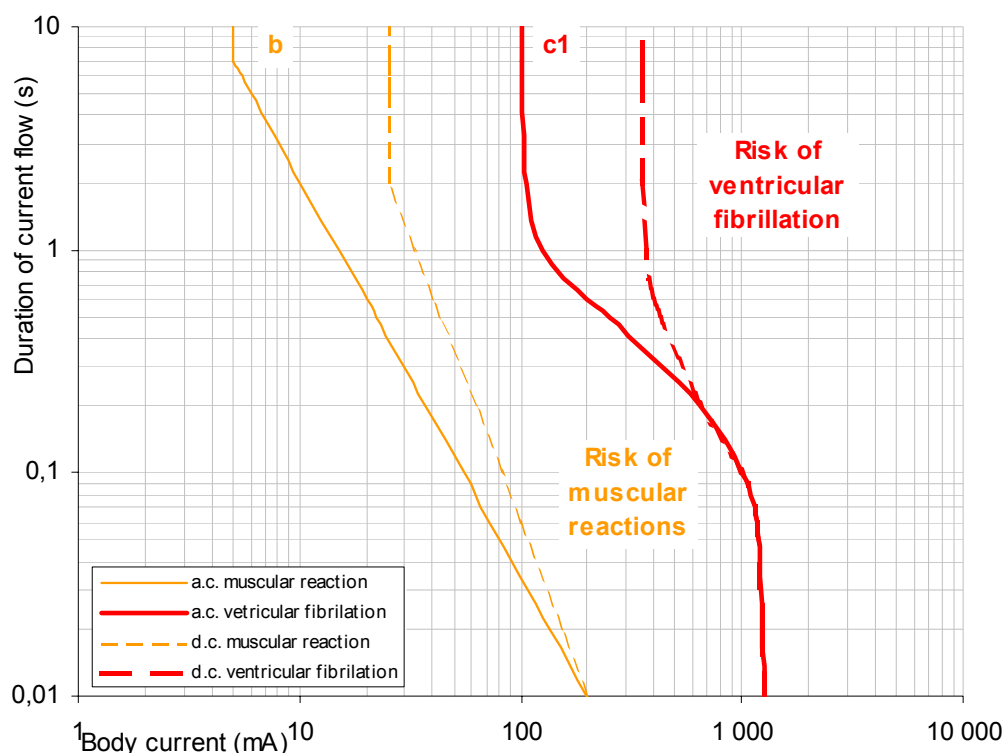


Figure 1 – Physiological thresholds for a.c. (50/60-Hz) and d.c. flowing hand-to-hand (transversely) through the human body

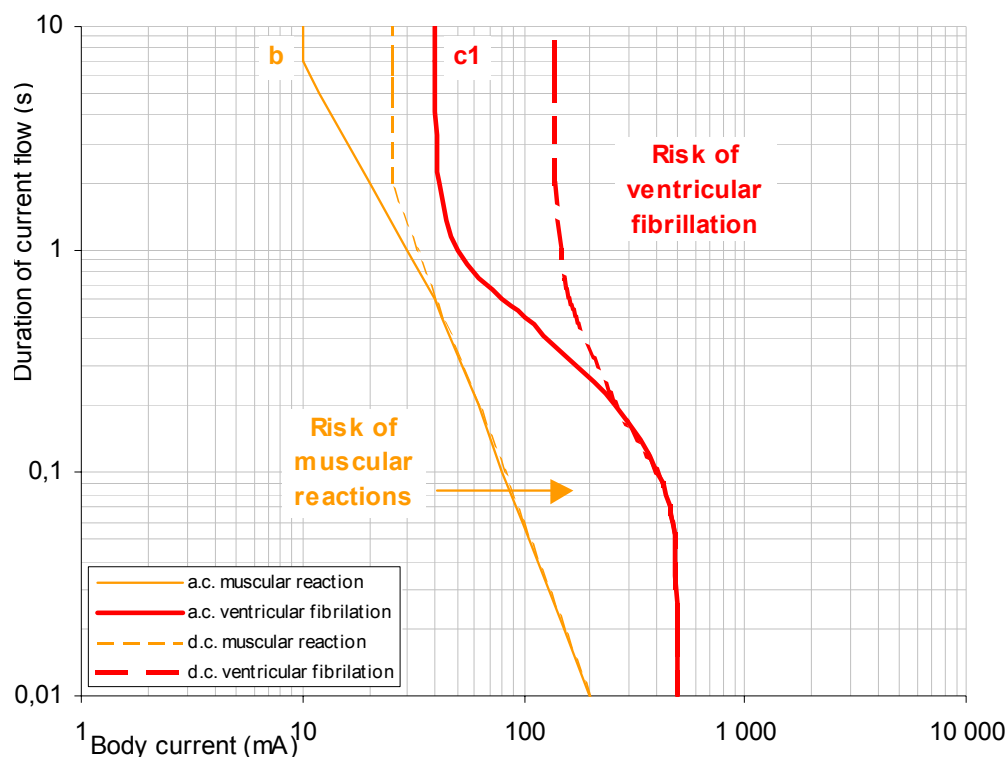


Figure 2 – Physiological thresholds for a.c. (50/60-Hz) and d.c. flowing from both hands to both feet (longitudinally) through the human body

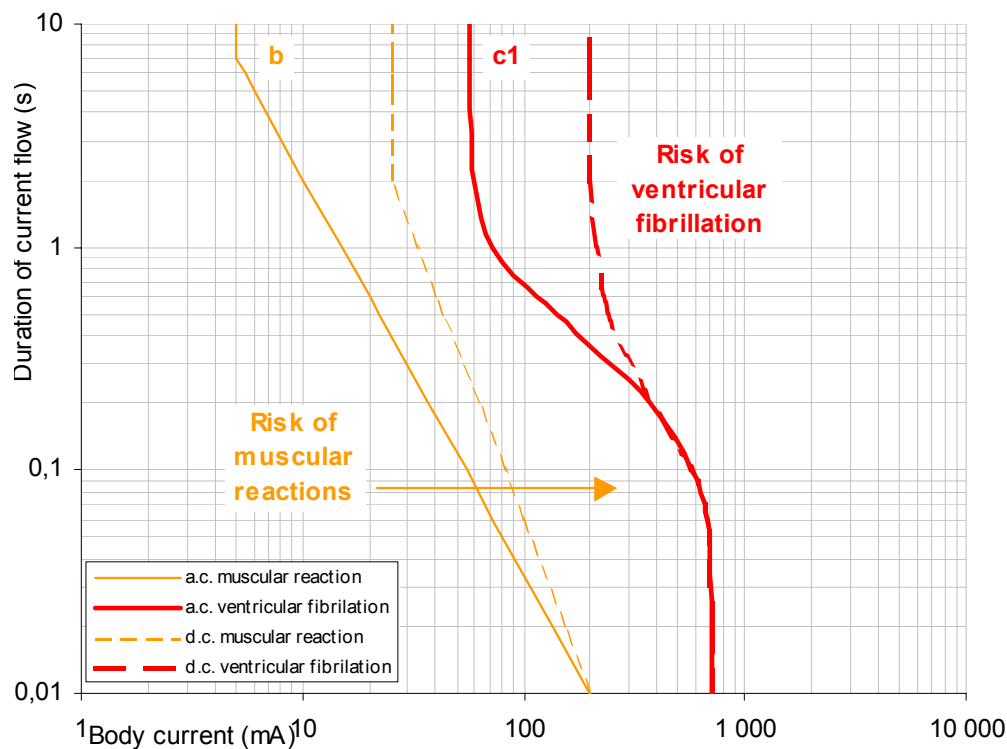


Figure 3 – Physiological thresholds for a.c. (50/60-Hz) and d.c. flowing from hand-to-seat (transversely) through the human body

For the determination of the voltage threshold, the following long duration current thresholds have been considered in this document. They have been determined from the figures 20 and 22 and table 12 of IEC 60479-1, which correspond to the upper end of the b or c₁ curves in Figure 1 to 3.

Type of threshold	Current	Current path	mA
Muscular Reactions	a.c.	Hand-to-Hand	5
		Both Hands-to-Feet ¹⁾	10
		One Hand-to-Seat	5
	d.c.	Hand-to-Hand	25
		Feet-to-both Hands	25
		Seat-to-one Hand	25
Ventricular Fibrillation	a.c.	Hand-to-Hand	100
		Both Hands-to-Feet	40
		One Hand-to-Seat	57
	d.c. ³⁾	Hand-to-Hand	350
		Feet-to-both Hands ²⁾	140
		Seat-to-one Hand ²⁾	200
Note 1: The values in this table refer to current through the torso. For a.c. the main concern is the inability to let-go which refers to the current through each arm. Therefore the total body current value in the table is doubled for longer current duration.			
Note 2: Current path in the direction of feet to hands is referred to as upward current. The ventricular fibrillation current threshold for a d.c. downwards current is about twice that of the current threshold corresponding to the upward current.			
Note 3: Lower current may cause other severe effects under other conditions such as respiratory arrest, albeit unlikely, as described in IEC 60479-1.			

Table 1: Current threshold values for each condition and for long duration

4.2. Body impedance

Touch voltage thresholds are related to touch current thresholds by the body impedance according to Ohm's Law. However, the application of Ohm's Law is not straightforward because the appropriate value of body impedance to use is a function of many factors. The selection of the proper value should include consideration of:

- the type of power source (a.c. or d.c.), and
- the pathway of the current through the body (one hand-to-one hand or both hands-to-both feet or one hand-to-seat), and

Note 1 : These different pathways have been selected for their characteristics. The reason comes from the body impedance model described in annex A. The voltage limits determined for the current path Hands-to Feet may be considered conservative compared to the current path from one Hand-to Feet.

- the area of contact with the skin, and
- the condition of the skin contact area (saltwater wet, water wet, dry), and
- duration of the current flow

Skin resistance changes as a function of the voltage across it. At low voltages, the change is reversible. It changes back to the original resistance quickly after the voltage is removed. At high voltage, permanent injury to the skin can occur. In this case, the change in skin resistance that results from the applied voltage is not reversible.

Note 2- A finger can be assumed to have a resistance of approximately 1000 ohms. Therefore contact with a finger tip rather than with the palm of the hand will significantly increase the body impedance. The conditions described by the contact with the palm of the hand is therefore conservative.

IEC 60479-1 contains information about body impedance that was obtained from measurements of live human volunteers and from measurements of cadavers. See Annex A for more details about body impedances and body impedance models. There are variations in impedance among individuals and this is shown in the tables by the percentile values.

Typically, physically larger people in the population would have lower internal body resistance because of their larger cross sectional area. Physically small people in the population would generally have higher internal body resistance. Some measurements [1] of body impedances show that the body impedance is not greatly influenced by the body weight. Therefore there is not sufficient correlation between the body weight (children or adults) and the physiological current values corresponding to a particular effect. Three percentiles of the population are considered in IEC 60479-1 publication (5th, 50th and 95th). This publication only considers the values of body impedances corresponding to the 5th percentile of the population which covers more than 95% of the population.

The body impedance only includes skin impedance and internal tissue impedance. External impedance from clothing including gloves or shoes are not considered in this document.

4.3. Circuit impedance external to the body impedance

It is assumed that the voltage source applied to the body has a low output impedance relative to the body impedance (which is the worst case). The magnitude of the body current is determined solely by the combination of the applied voltage and the human body impedance. Consideration of any significant circuit impedance that might be in series with the body that can affect the available body current from the voltage source is outside the scope of this report.

Note: In some instances with large inductive impedance in series with the body, the touch voltage might be higher than the open circuit voltage of the source. This effect can become significant for 50Hz / 60Hz at inductances larger than 100mH.

4.4. Environmental situations

The situations considered in this report are as follows:

- 50/60 Hz alternating sinusoidal voltage with no d.c. component or direct voltage with no alternating component.
- saltwater wet, water wet and dry

NOTE 1 – Dry condition of skin is considered as normal indoor condition, water wet condition of skin is considered as immersed for more than 1 minute into a normal water (average value $\rho = 35 \Omega.m$, pH = 7,7 - 9), and saltwater wet condition of skin is considered as immersed for more than 1 minute into a solution of 3% NaCl in water (average value $\rho = 0,25 \Omega.m$, pH = 7,5 - 8,5).

Perspiration may be considered to lie between water wet and saltwater wet condition. The conductivity of some sea water is slightly higher than the saltwater wet condition.

- hand-to-hand contact or hands-to-feet contact or hand-to-seat contact with accessible conductive parts,

- large contact, medium area contact, or small area contact with accessible conductive parts,

A large, full hand contact (L) has surface contact area of the hand of 82 cm². A medium contact area (M) is 12,5 cm² and might represent touching a conductive part in the palm of each hand. A small contact area (S) is considered to be 1 cm² and might represent touching a small conductive part with the hand. All contacts, except for hand-to-seat, are assumed to be symmetrical for the purpose of this analysis. It is assumed that contact between each foot and a conductive supporting surface will be the same size as for each hand surface contact.

The worst case presented in this document corresponds to the following situation: a.c. current, long duration, saltwater wet condition and large contact area.

It should be noted that contact area may be affected by the use of conductive tools.

4.5. Touch voltage thresholds as a function of duration

Based on the human body impedances and on the current – time curves as provided in IEC 60479-1, a set of diagrams in Annex C provide the maximum time acceptable for a given touch voltage applied to a human body. These curves have been established by using the method as described in Annex B with the model as described in Annex A.

These curves shall be used as a guide by IEC Technical Committees when prescribing the maximum disconnecting time of the protective device used for the automatic disconnection of supply. For more details, see Annex C.

The following flow-chart is provided to direct the reader to the appropriate figure (see Annex C) showing voltage threshold information based on the situation of interest:

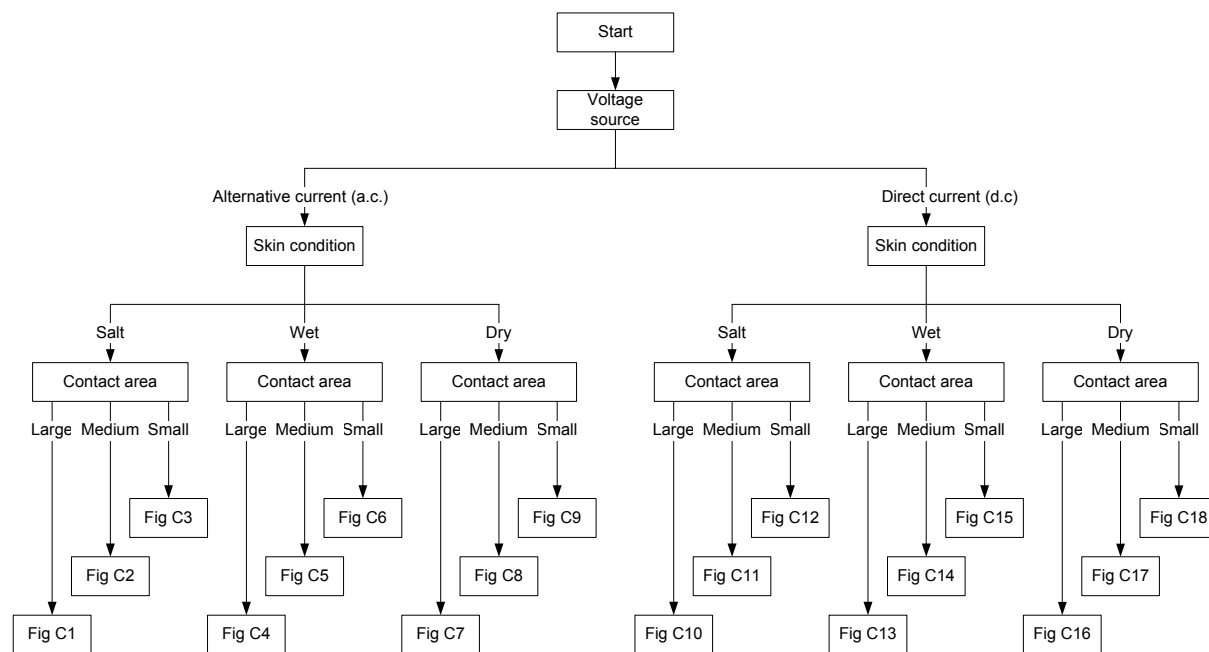


Figure 7 : Flow chart to be used for the selection of the appropriate figure providing the maximum duration for each touch voltage threshold

Appendix B illustrates the method used to calculate touch voltages based on touch currents and body impedances.

4.6. Touch voltage thresholds for long durations

The following tables represent an extract of the figures in Annex C for long durations. Appendix B illustrates the method used to calculate touch voltages based on touch currents and body impedances.

Technical Committees may use these voltage thresholds to set voltage limits in their product standards using appropriate risk factors.

For alternating current 50/60 Hz

Muscular Effects Current threshold (mA)	a.c. touch voltage thresholds for long duration (Volts)								
	Saltwater wet			Water wet			Dry		
	Large contact	Medium contact	Small contact	Large contact	Medium contact	Small contact	Large contact	Medium contact	Small contact
Hand to Hand 5	5	9	27	7	25	93	11	41	104
Hands to Feet 10	6	10	28	7	26	93	12	41	105
Hand to Seat 5	3	5	14	4	13	47	6	21	52

Ventricular fibrillation Current threshold (mA)	a.c. touch voltage thresholds for long duration (Volts)								
	Saltwater wet			Water wet			Dry		
	Large contact	Medium contact	Small contact	Large contact	Medium contact	Small contact	Large contact	Medium contact	Small contact
Hand to Hand 5	90	160	257	98	165	260	99	165	260
Hands to Feet 10	22	39	96	27	73	152	35	85	152
Hand to Seat 5	30	52	102	34	68	103	37	68	103

For direct current

Muscular Effects Current threshold (mA)	d.c. touch voltage thresholds for long duration (Volts)								
	Saltwater wet			Water wet			Dry		
	Large contact	Medium contact	Small contact	Large contact	Medium contact	Small contact	Large contact	Medium contact	Small contact
Hand to Hand 5	24	44	112	29	81	156	43	89	156
Hands to Feet 10	14	24	64	17	53	135	28	68	135
Hand to Seat 5	13	24	57	16	42	79	23	46	79

Ventricular fibrillation Current threshold (mA)	d.c. touch voltage thresholds for long duration (Volts)								
	Saltwater wet			Water wet			Dry		
	Large contact	Medium contact	Small contact	Large contact	Medium contact	Small contact	Large contact	Medium contact	Small contact
Hand to Hand 5	263	351	467	264	353	470	264	353	470
Hands to Feet 10	75	129	227	82	150	230	94	150	230
Hand to Seat 5	93	136	211	95	137	213	95	137	213

Table 2 : Tables providing the minimum touch voltage threshold for a.c. and d.c. and corresponding to muscular reaction and ventricular fibrillation

Appendix B illustrates the method used to calculate touch voltages based on touch currents and body impedances.

4.7. Voltage threshold as a function of contact area

The following graphs show threshold touch voltage versus contact area. It is assumed that since the plotted points are close to being in-line when plotted on a log-log scale, the best fit curve to represent points between those actually calculated will be on a line joining the calculated points on the log-log scale.

These threshold charts are intended to document the effect of contact area, which might be used in products as a key design parameter for limiting the effect of touch voltage. It should be noted that contact area may be affected by the use of conductive tools.

Note: Annex D illustrates examples of maximum contact areas for traditional accessible voltages.

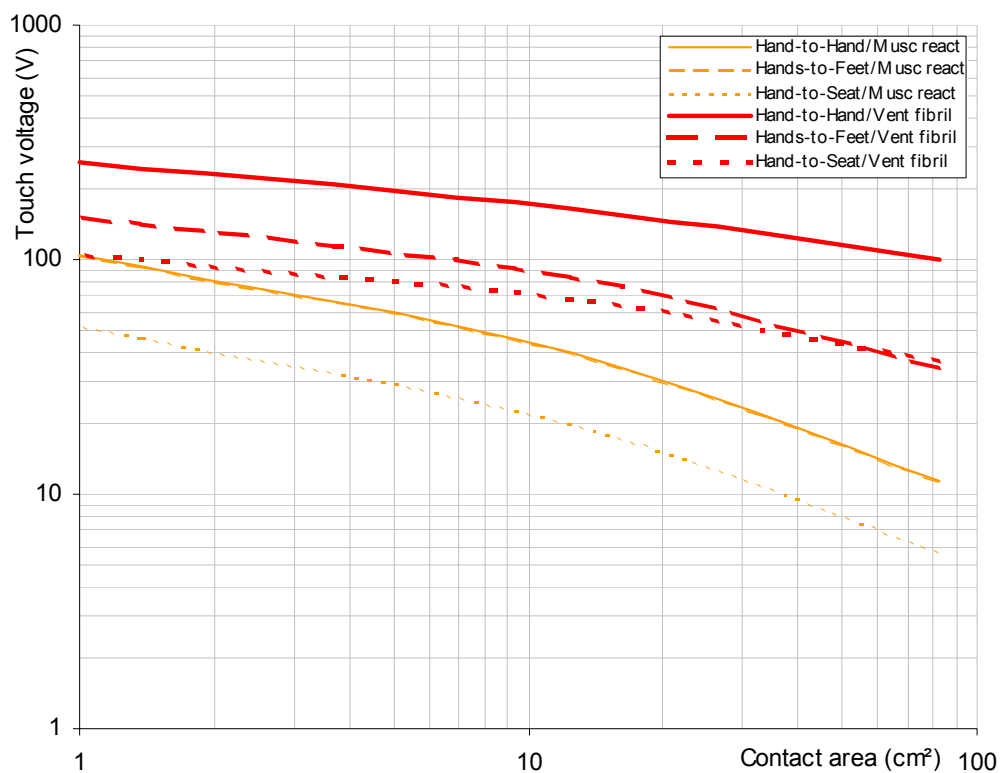


Figure 4 – Minimum touch voltage threshold corresponding to a.c. and dry condition for muscular reaction and ventricular fibrillation

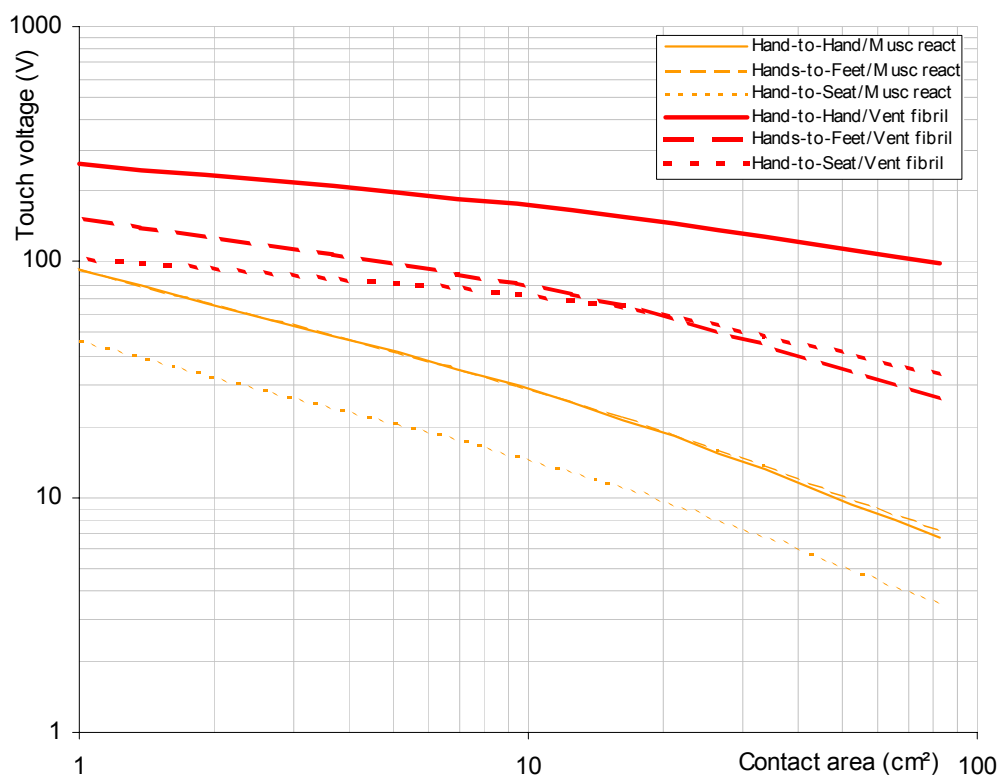


Figure 5 – Minimum touch voltage threshold corresponding to a.c. and water wet condition for muscular reaction and ventricular fibrillation

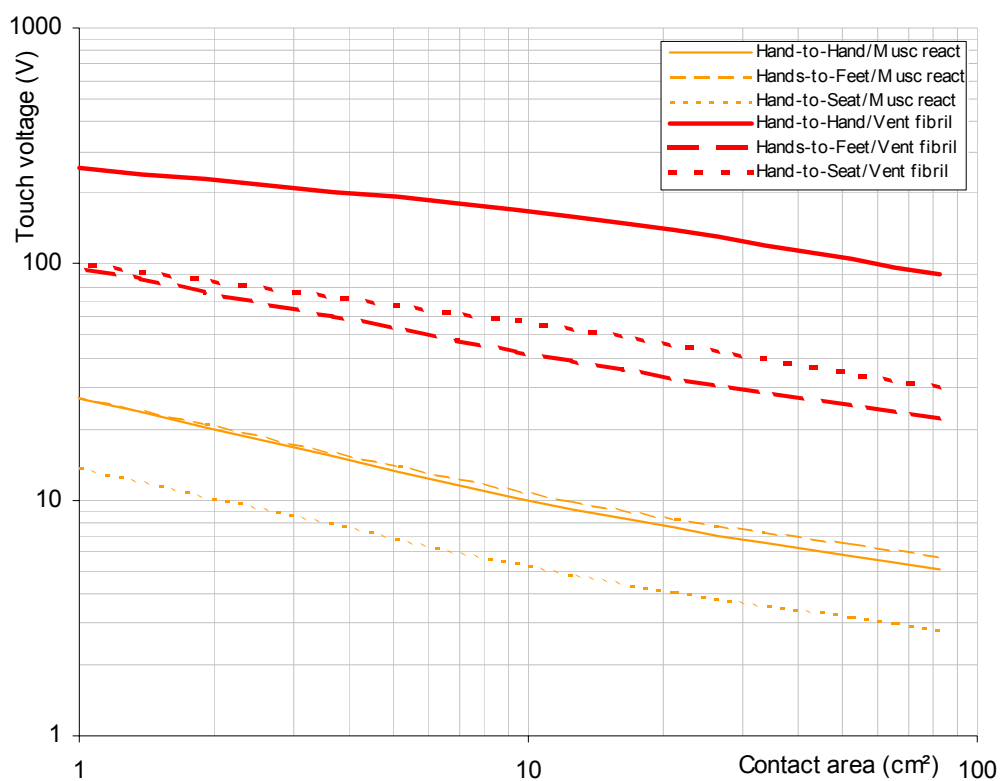


Figure 6 – Minimum touch voltage threshold corresponding to a.c. and saltwater wet condition for muscular reaction and ventricular fibrillation

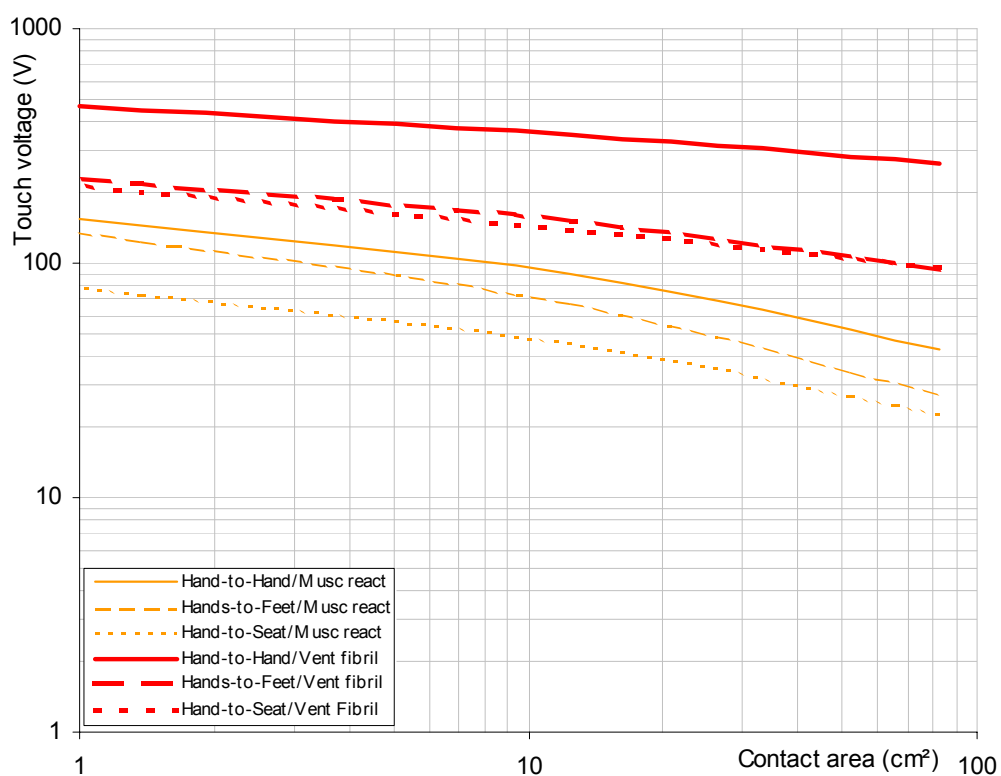


Figure 7 – Minimum touch voltage threshold corresponding to d.c. and dry condition for muscular reaction and ventricular fibrillation

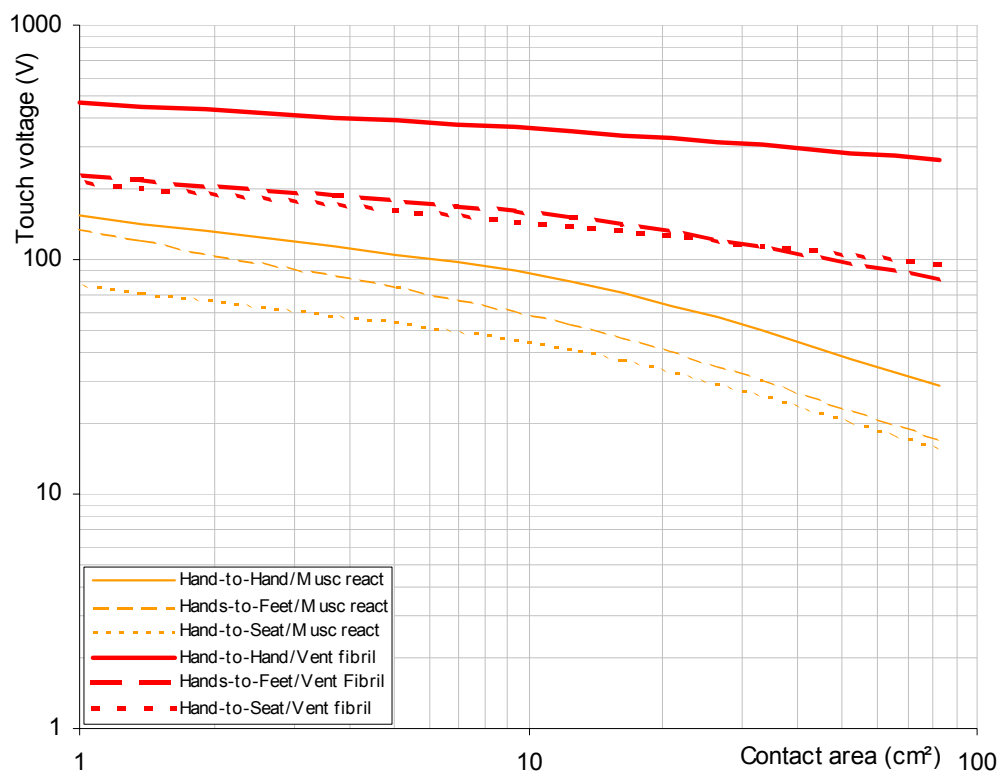


Figure 8 – Minimum touch voltage threshold corresponding to d.c. and water wet condition for muscular reaction and ventricular fibrillation

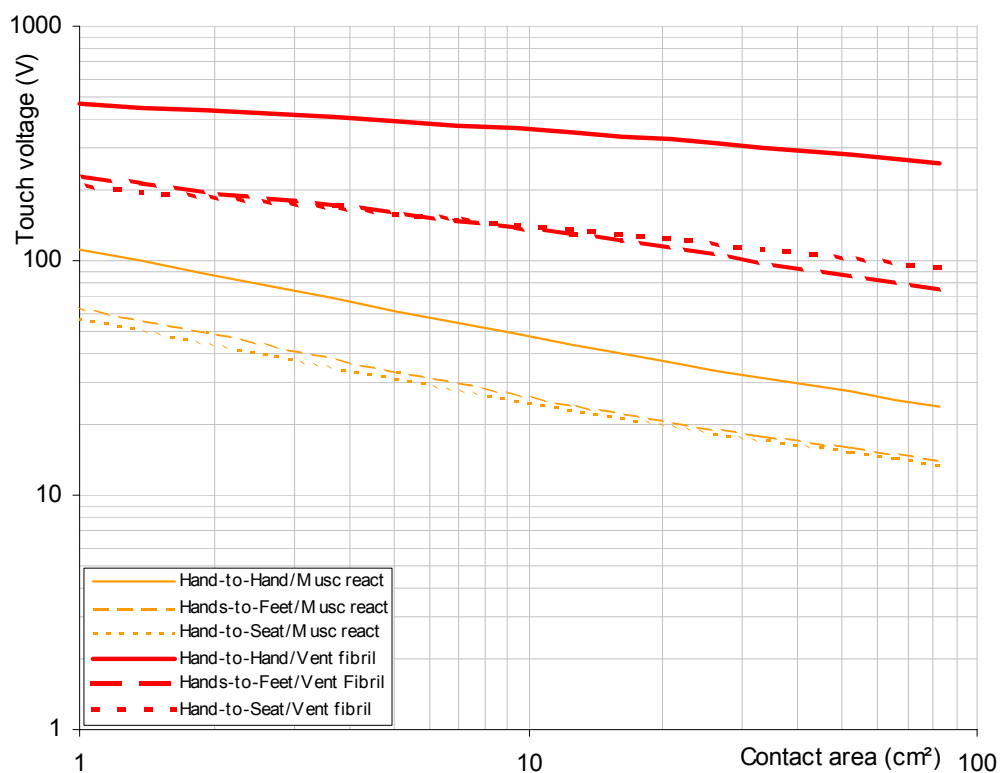


Figure 9 – Minimum touch voltage threshold corresponding to d.c. and saltwater wet condition for muscular reaction and ventricular fibrillation

5. Limits of applicability

5.1. Higher frequency alternating voltages and currents

This document discusses only 50/60 Hz sinusoidal alternating voltage and pure direct voltage having no significant alternating component. Higher frequency alternating voltage would require a more complex body impedance model and adjustments of the current thresholds for the unwanted physiological effects.

As frequency rises from 50/60 Hz, the human body impedance decreases while the physiological effect of current decreases [2]. However, the decrease in body impedance begins to occur at a lower frequency than the frequency at which the increase in threshold current for the physiological effect begins to occur. The result is that as frequency rises from 50/60 Hz, the threshold touch voltage for a physiological effect such as startle reaction, inability to let go, or ventricular fibrillation decreases before it begins to increase with rising frequency. The “dip” in the threshold voltage for these effects occurs between approximately 100 Hz to a few kilohertz. The voltage threshold for the same physiological effects discussed in this report from voltage sources operating at a frequency between approximately 100 Hz and a few kilohertz might be on the order of about half of the voltage threshold determined for 50/60-Hz sources.

IEC 60990 - Measurements of touch currents and protective conductor currents makes proper allowance for high frequency touch current according to the conditions given by IEC 60479.

5.2. Immersion

Voltage thresholds are not easily used for applications that involve immersion of body parts, such as for products used in swimming pools, spas, bathtubs, and the like. One complication is that the presence of the body in the water distorts an electric field in the water. Another complication is the large number of possible pathways for current to enter and exit the body over very large areas of skin. Movement of the body in the water with respect to the direction of the electric field can change the body current and therefore the effect of the electric field on the body. The orientation of the body with respect to the electric field determines the amplitude of the current through different parts of the body, and that affects the types of physiological effects that can occur as a result of the electric field.

Electric current through an immersed swimmer's body can include the person's head in the water, the effect of current through the head can interfere with the person's ability to swim. Drowning can occur in addition to the other physiological effects including muscular effects that are normally addressed.

Without current-limiting in the electrical source, adverse effects can be caused when a person is immersed in water with only a few volts available. Products used in immersed body applications generally should be current-limited and evaluated based on the current-limiting features, not voltage. Therefore this document does not cover situations where the human body is immersed.

5.3. Medical applications

Special consideration needs to be given to medical environments where highly current-sensitive patients (e.g. catheterized patients) may be present. Both current and voltage thresholds might be considerably different for these special situations. The voltage threshold information developed as part of this work are not intended to apply to medical devices or medical environments.

Annex A

Body impedance

(informative)

A.1. Values of body impedance

Several tables in IEC 60479-1 show values of total hand-to-hand body impedance for the 5th, 50th, and 95th percentiles of the population for dry, water wet or saltwater wet conditions. Full-hand contact, large surface electrodes, medium size of surface contact and small size of surface contact are considered. Tables contain values for 50/60 Hertz alternating voltage; other table contains values for direct voltage.

Only values corresponding to the 5th percentile (representing more than 95% of the population) of the population were considered in this document. The body impedance values corresponding to this percentile of the population are smaller than values corresponding to higher percentile of the population. Therefore considering the 5th percentile values is conservative from a safety point of view because they correspond to higher current through the body.

When voltage is applied across a body, the skin suffers many local breakdowns of its electrical insulating properties. This process causes lowering of the overall skin resistance, and takes time to occur – generally over several tens of milliseconds. The greater the change in voltage, the greater the change in skin resistance. The measured body impedance reported in the available data sources apply to specific times when the measurement was made after the application of voltage across the body. For example, measurements of cadavers were made after 3 seconds of body current flow. When a living volunteer subject was involved, the time of measurement was sometimes taken as the impedance was still decreasing from the applied voltage, but the comfort and safety of the volunteer had to be considered. Measurements of living subjects were taken after 0,1 seconds or 20 to 25 milliseconds of body current flow depending on the potential for harm to the subject. This might be a source of uncertainty in the values used for the touch voltage calculations because steady state conditions may not have been reached. Changes in skin resistance are quickly reversible for the lower voltage levels where permanent injury to the skin has not occurred.

Values of total hand-to-hand body impedance for the population (5th, 50th, and 95th percentiles) for the same large-area dry contact, but with direct current (with no ac component), are shown in Table 10 of IEC-60479-1.

The tables below are examples of the application of the data in IEC 60479-1

Touch voltage – Volts	Values in ohms that are not exceeded for the percentile rank		
	5% of the population	50% of the population	95% of the population
25	1 750	3 250	6 100
50	1 375	2 500	4 600
75	1 125	2 000	3 600
100	990	1 725	3 125
125	900	1 550	2 675
150	850	1 400	2 350
175	825	1 325	2 175
200	800	1 275	2 050
225	775	1 225	1 900
400	700	950	1 275
500	625	850	1 150
700	575	775	1 050
1 000	575	775	1 050
Asymptotic value	575	775	1 050

Table A1: Total body impedance in ohms for dry, hand-to-hand, 50/60-Hz a.c., large surface area contact (IEC 60479-1 Table 1)

Touch voltage – Volts	Values in ohms that are not exceeded for the percentile rank		
	5% of the population	50% of the population	95% of the population
25	2 100	3 875	7 275
50	1 600	2 900	5 325
75	1 275	2 275	4 100
100	1 100	1 900	3 350
125	975	1 675	2 875
150	875	1 475	2 475
175	825	1 350	2 225
200	800	1 275	2 050
225	775	1 225	1 900
400	700	950	1 275
500	625	850	1 150
700	575	775	1 050
1 000	575	775	1 050
Asymptotic Value	575	775	1 050

Table A2: Total body impedance in ohms for dry, hand-to-hand, d.c., large surface area contact (IEC 60479-1 Table 10)

The asymptotic values indicated in Table A.1 and A.2 are the minimum total body impedance values that occur when the skin impedance is completely eliminated, such as when the voltage across the body is very high. At very high voltages, the skin is destroyed leaving zero skin impedance. Then, without the skin, the total body impedance equals the internal body resistance.

A.2. Models of body impedance

The body impedance model used in this analysis to represent a person's body is a 3-component model consisting of a resistor in series with a parallel combination of a resistor and capacitor. The internal body is represented by the series resistor. The parallel combination of resistor and capacitor represents the combined skin at the entry and exit of the body current. In order to simplify the calculations which can be difficult if two or more voltage-sensitive resistors are operating at different voltages, it is assumed here that either

- the entry and exit skin is identical in area, moisture, etc. to make the model symmetrical, or
- the impedance of one skin contact area is much greater than the impedance of the other skin contact and therefore the lower-impedance skin contact can be neglected as insignificant in the calculations leaving only one voltage-sensitive resistor.

A 5-component body impedance model that treats the entry skin and exit skin independently would be more versatile and therefore more useful to handle more actual situations. However, the mathematical complexity involved in solving the model would be raised to a new level.

Figure A.1 shows the model for the hand-to-hand case which was used in all of the measurements of total body impedance. The two hand skin contacts with the electrodes are identical, and therefore they can be combined into a single parallel combination of resistor and capacitor in the model. (When the two skin impedances are identical, the line a-b shown in the figure below in the lower left-hand circuit diagram will have no current flowing through it due to the balance of the components and this equipotential line a-b can therefore be eliminated) The skin capacitor in the 3-component model is half the actual skin contact capacitance of each hand because the two hand capacitors are in series. The skin resistor in the model is double the skin contact resistance of each actual hand. The voltage across the skin in the model is double the voltage across the skin contact of each actual hand. The series resistor in the model is equal to the actual internal body resistance (the asymptotic value of body impedance in the table) from hand-to-hand.

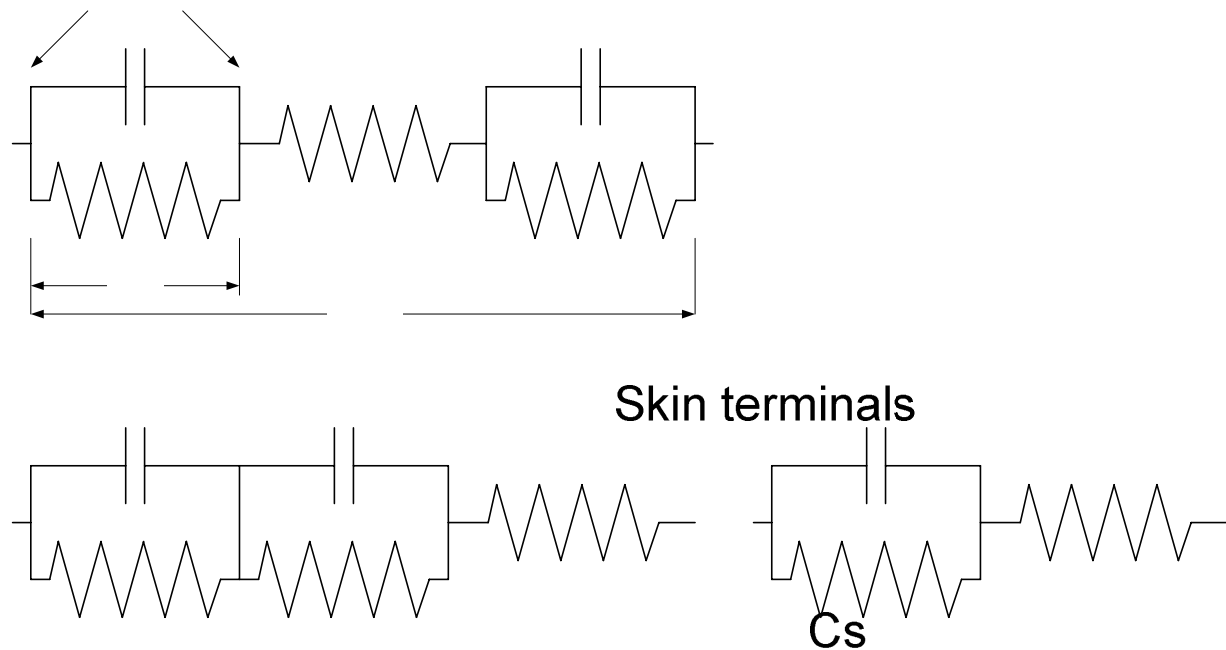
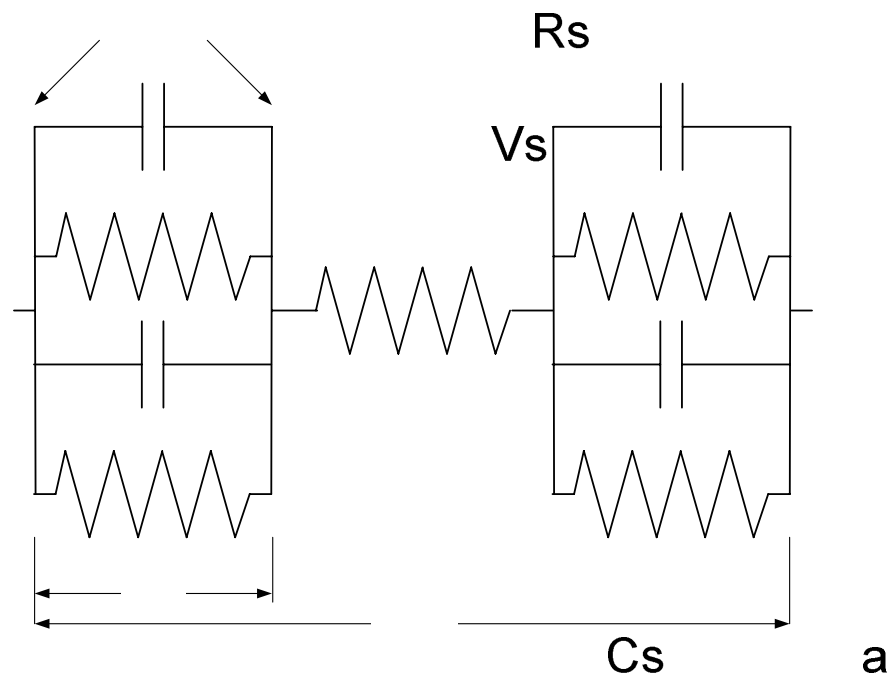


Figure A.1 Model for Hand-to-Hand contact

In the Figure A.2, the four hand/foot skin contacts with the electrodes are identical, and therefore they can be combined as shown into a single parallel combination of resistor and capacitor in the model. When the skin impedances are identical, the line a-b shown in the figure below in the lower left-hand circuit diagram will have no current flowing through it due to the balance of the components and this equipotential line a-b can therefore be eliminated. The skin capacitor in the model is equal to the skin contact capacitance of each hand. The skin resistor in the model is equal to the skin contact resistance of each actual hand. The voltage across the skin is equal to double the voltage across the skin contact of each actual hand. The series resistor in the model is equal to the hand-to-hand internal body resistance (the asymptotic value of body impedance) modified by a factor derived from Figure 3 of IEC-60479-1 which is the ratio of hands-to-feet resistance divided by the hand-to-hand resistance.



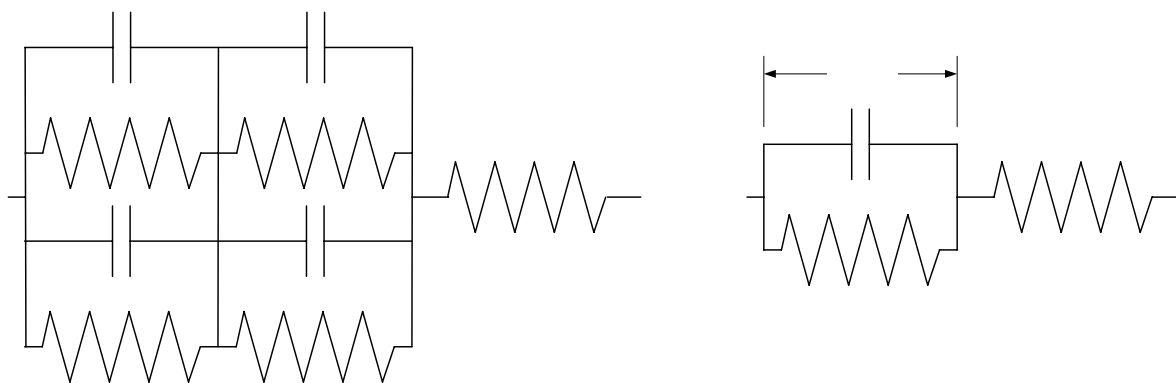
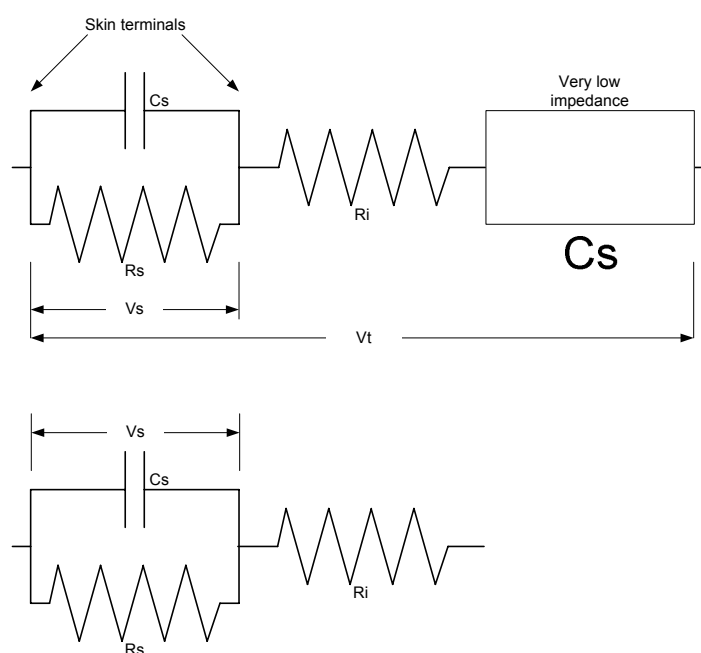


Figure A.2: Model for Hands-to-Feet contact

C_s

a

In Figure A.3, the impedance of the skin contact with the electrode at the seat is assumed to be very low in value relative to the impedance of the hand skin contact. Therefore, the seat impedance is neglected in the model. The skin capacitor in the model is equal to the skin capacitance of the actual hand contact. The skin resistor in the model is equal to the skin resistance of the actual hand contact. The voltage across the skin in the model is equal to the voltage across the skin of the actual hand contact. The series resistor in the model is equal to the hand-to-hand internal body resistance (the asymptotic value of body impedance) modified by a factor derived from Figure 3 of IEC 60479-1 which is the ratio of hand-to-torso resistance divided by the hand-to-hand resistance.



R_s

b

Figure A.3: Model for Hand-to-Seat contact

The value of the internal body resistance for the hand-to-hand pathway is assumed to be equal to the asymptotic value of body impedance in the IEC 60479-1 tables. In each table, the asymptotic value is the lowest body impedance value at the high-voltage end where it can be assumed that the skin has no contribution to the total body impedance. This value is modified according to the ratios suggested by Figure 3 of IEC 60479-1 when the pathway of body current is changed.

The values of skin resistance can span a very wide range depending on the skin contact area and the moisture and impurities associated with the contact.

Annex B

Touch voltage – an explanation of a method to derive estimates of touch voltages thresholds for muscular reactions and ventricular fibrillation from body impedance tables and current limits in IEC 60479-1

(informative)

B.1 General

Publication IEC 60479-1 contains information about both body impedance and body current thresholds. This analysis will suggest a method of combining the body impedance information and the current threshold information to derive touch voltage threshold information that is fully compatible with IEC 60479-1.

This informative Annex will review and explain the approach adopted to develop the new touch voltage thresholds based on this new information in IEC 60479-1.

According to models of the human body, physically larger people tend to have lower internal body impedance as compared to physically smaller people. Studies have been carried out and show that total body impedance and body weight are actually largely independent. However, the small interdependence of these variables makes ordinary statistical methods of estimating touch voltages thresholds against the touch current unsuitable. The method used in this specification is to assume independence using the 5th percentile figure in IEC 60479-1. This is probably more reasonable but a less conservative approach.

B.2 Calculation methods

B.2.1 Numbers of parameters

The number of combinations that need to be considered from the contributing variables affecting touch voltage thresholds can be very large.

According to IEC 60479-1, many parameters influence the values of the human body impedance. The specific influencing parameters considered in this analysis include:

Influencing parameter	Type	Number of parameters	Cumulative number of combinations
Nature of current	a.c. d.c.	2	2
Current path	Hand-to Hand Hands-to-Feet Hand-to-Seat	3	6
Skin condition	Dry condition Waterwet condition Saltwater wet condition	3	18
Skin contact area	Large area Medium are Small area	3	54
Touch voltage	25V – 50V – 75V – 100V – 125V – 150V – 175V – 200V – 225V – 400V – 500V – 700V – 1000V	13	702
Percentile of the population	5 th	1	702

Table B1. Nature and number of the parameters influencing the human body impedance and taking into consideration by IEC 60479-1

Other parameters will then be introduced within the calculation of touch voltage such as:

Influencing parameter	Type	Number of parameters	Cumulative number of combinations
Physiological thresholds	Muscular reactions Ventricular fibrillation	2	1404
Skin capacitance	0.01 $\mu\text{F}/\text{cm}^2$ 0.03 $\mu\text{F}/\text{cm}^2$ 0.05 $\mu\text{F}/\text{cm}^2$	3	4212
Time of current flow through the human body *	0.01 s – 0.02 s – 0.06 s – 0.1 s – 0.2 s – 0.6 s – 1 s and 10 s.	8	33696

* For a good definition of the logarithmic curves the times shown have been selected.

Table B2. Additional parameters influencing the human body impedance

This means that 33696 individual calculations need to be tabulated. A good way to perform a great number of calculations from the basic data, which are discrete values, is to use a computer spreadsheet.

B.2.2 General method

IEC 60479-1 provides impedance values of human body for all situations as described in table B1 but only for the Hand-to-Hand current path:

Therefore all impedances of human body for the two other current paths (2 hands-to-2 feet and hand-to-seat) have to be determined for each skin condition and each touch voltage. From these estimations it is possible to calculate the touch voltage by interpolation for each current threshold. This comparison is done for each value of time duration.

B.2.3 Hypothesis and calculation limit

B.2.3.1 Skin capacitance determination

The first operation is the evaluation of the skin capacitance which is known from experiments [3] to [8]. These experimental values of capacitance are in the range of 0.01 $\mu\text{F}/\text{cm}^2$ to 0.05 $\mu\text{F}/\text{cm}^2$.

Considering this range, calculations have been done considering the following 3 capacitance figures:

- minimum value : 0,01 $\mu\text{F}/\text{cm}^2$
- medium value : 0,03 $\mu\text{F}/\text{cm}^2$
- maximum value : 0,05 $\mu\text{F}/\text{cm}^2$

From these values and the skin contact area it is possible to have a range of figures for the skin capacitance corresponding to each contact area. Results of calculation of touch voltages have shown that small differences exist over the range of skin capacitance therefore a single value of skin capacitance was chosen to be consistent with the body impedances provided by IEC 60479-1.

B.2.3.2 Skin resistance as a function of time

The voltage applied to skin is zero before current begins to flow through the skin but, at the first instant, the touch voltage is present and the current starts to flow. It takes a fraction of a second for the skin resistance to adjust to the potential difference across it. It has been estimated from test

results that a decreasing exponential variation of the skin resistance may provide an acceptable approximation of the phenomenon. A time constant of 50 ms is used in this report [9].

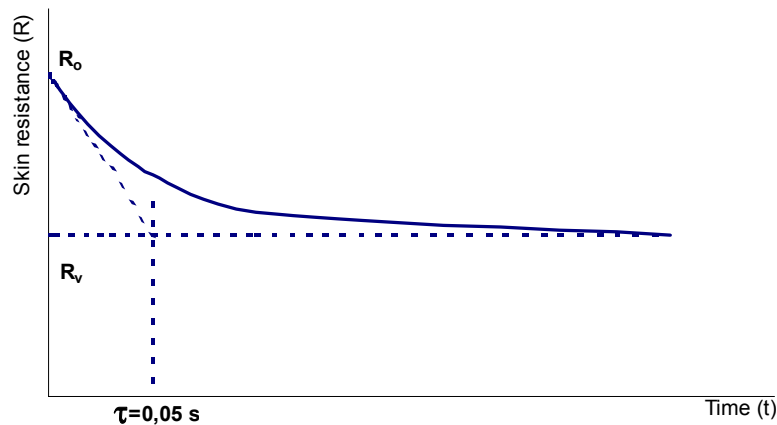


Figure B1: Estimation of the variation of the skin resistance as a function of the electric shock duration

$$(R - R_v) = (R_0 - R_v)e^{-t/0,05} \quad \text{B.I}$$

with

R_0 : skin resistance in absence of touch voltage

R_v : skin resistance after an infinite time of voltage application

τ : time constant

The value of R_s is thus also function of the time of the current flow through the human body. This value $R_s(t)$ is given by the following formula:

$$R_s(t) = R_s + (R_s(0) - R_s)e^{-t/0,05} \quad \text{B.II}$$

Initially the current will change as the skin resistance adjusts to the final skin voltage. For short durations the current ceases before the skin resistance is fully adjusted. This equation is used between the onset of current flow and the instant when the current is switched off. This will primarily introduce correction for short durations up to three time constants.

B.2.3.3 Method for measuring the impedance of human body

Human body impedance values provided by IEC 60479-1 are supposed to correspond to long touch duration. Skin resistance depends on the voltage directly applied to the skin. But in case of touching “high” voltages in severe conditions (such as water-wet skin and large skin contact area) measurements done on volunteers for the determination of body impedance are very painful. In order to avoid too much pain and risk to these persons, the application time of the touch voltage was reduced. In such cases the measured impedances may be higher than actual impedances that might have been achieved if the voltage were applied across the skin for a longer time.

B.2.3.4 Limit values of human body impedances

IEC 60479-1 provides impedances of the human body, but all cases necessary for calculation of touch voltages corresponding to physiological effects are not provided. They have to be calculated indirectly.

a) Measurement of human body impedance has been performed from a minimum voltage of 25 V. But according to B.2.3.2 the value of R_o is necessary. In this document a linear extrapolation from the 25 V and 50 V values was used in order to make a conservative estimate of the impedance value of the human body at 0 V.

b) For severe conditions (water-wet skin or saltwater-wet skin) no measurements have been done for touch voltages exceeding 200 V. These test conditions are too severe due to the very strong pain felt by volunteers. At a touch voltage on the order of 1 000 V only the internal impedance remains and no skin impedance should be considered.

B.2.3.5 Interpolations

Comparison of current flowing through the human body with the current thresholds for different physiological effects may require interpolation between calculated values which was done on a logarithmic plot.

B.2.3.6 Accuracy

Because of the statistical behaviour of the basic data, the accuracy of the touch voltage threshold values derived from calculations cannot be estimated.

B.3 Calculation

B.3.1 Calculation algorithms of the impedance for a.c.

All formulae used in this subclause are directly derived from the model described in Annex A for each current path.

B.3.1.1 Hand-to-Hand path

a) Hand-to-hand current path

The starting point corresponds to the values provided by the IEC 60479-1 for the human body impedance Z_{h-h} for a hand-to-hand current path and for each touch voltage $V_{t h-h}$ (hand-to-hand)

The hand-to-hand current I_{h-h} is given by:

$$I_{h-h} = \frac{V_{t h-h}}{Z_{h-h}} \quad \text{B.III}$$

For further calculations corresponding to other current paths, it is necessary to calculate the different component parts of the body impedance.

b) Internal resistance

The internal resistance $R_{i h-h}$ corresponds to the resistance of the tissues located between both hands. They include the arms and the torso when current flows transversely. It is difficult to measure such a resistance, but nevertheless an indirect estimation is possible. For higher voltage, measurements of the hand-to-hand impedance becomes asymptotic for a value corresponding to this internal resistance for the current path under consideration. This is explained by the fact that skin breaks down at this voltage and skin resistances and skin capacitances are totally by-passed.

From a practical point of view, we are considering that the internal resistance is equal to the total body impedance measured at a voltage on the order of 1 000 V.

$$R_{i\ h-h} = Z_{h-h} \text{ at } \approx 1000V \quad \text{B.IV}$$

c) Skin capacitance

Estimation of the skin impedance value is necessary. To do this, estimation of the skin capacitance C_s is needed. This skin capacitance is calculated from the skin capacity variation per area C_s/S_s (from 0.01 to 0.05 $\mu\text{F}/\text{cm}^2$) and from the surface of contact S_c :

$$C_s = S_c \times \left(\frac{C_s}{S_s} \right) \left[\begin{array}{l} C_s/S_s = 0.05 \mu\text{F}/\text{cm}^2 \\ C_s/S_s = 0.01 \mu\text{F}/\text{cm}^2 \end{array} \right] \quad \text{B.V}$$

d) Skin resistance

The calculation of the skin resistance is more difficult and has to be done by successive approximation, that can easily be solved by calculation software.

Skin resistance is part of the total human body impedance. But this resistance depends on the voltage that is directly applied to the skin, which depends itself on the split of the total human body impedance.

This results in finding the right value for the skin resistance R_s such as Z_{h-h} given by the following formula becomes equal to the value given by the IEC 60479-1 document.

$$Z_{h-h} = \frac{R_{i\ h-h} \sqrt{(2\pi f)^2 + \left(\frac{R_{i\ h-h} + 2R_s}{R_{i\ h-h} \times 2R_s \times \frac{C_s}{2}} \right)^2}}{\sqrt{(2\pi f)^2 + \left(\frac{1}{2R_s \times \frac{C_s}{2}} \right)^2}} \quad \text{B.VI}$$

where:

f is the frequency of the current passing through the human body.

NOTE: For some cases, it has been impossible to estimate the correct value of R_s in order to match the value provided by IEC 60479-1. This comes from the value of the skin capacitance value which becomes so small that the skin resistance is nearly short-circuited. For this reason this report uses the minimum value of skin capacitance.

The formula for Z_{h-h} depends also on $R_{i\ h-h}$, which corresponds to the resistance of the internal tissue for a hand-to-hand current path.

e) Readjustment of the skin resistance

The value found for R_s corresponds to a resistance for long duration of touch voltage (it has been supposed that the human body impedance value Z_{h-h} corresponds to a long touch voltage duration, long enough for R_s to adjust itself to the voltage directly applied to the skin). For shorter durations (less than three time constants) the skin resistance does not have time enough to be completely adjusted. This calculation adjusts the curve as a function of time as given in B.2.3.2.

$$R_s(t) = R_s + (R_s(0) - R_s) e^{-t/0.05} \quad \text{B.VII}$$

But to apply this algorithm, an estimation of $R_s(0)$, which is the skin resistance before the electric shock, is needed.

f) Estimation of the initial skin resistance

Linear extrapolation of the curve giving Z_{h-h} as a function of V_t provides an estimation of the initial value of $Z_{h-h}(0)$ which permits the calculation of $R_s(0)$.

The graph below (Figure B2) enables extrapolation to give the initial value of the hand-to-hand impedance $Z_{h-h}(0)$. Linear extrapolation provides a value of 2125 Ω for the hand-to-hand body impedance at 0 V.

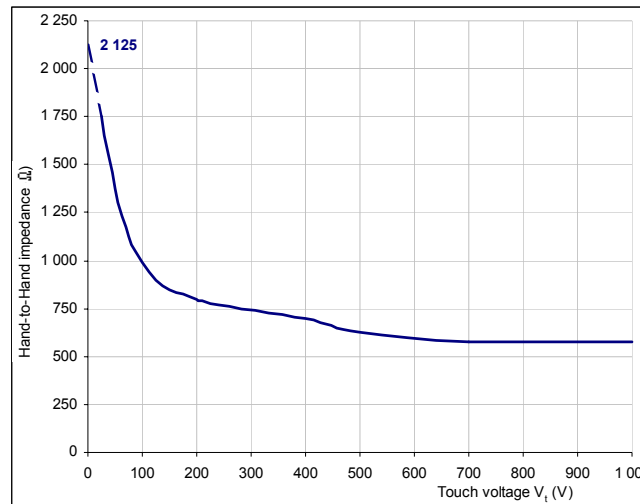


Figure B2: Example of extrapolation of the hand-to-hand body impedance at 0 V in dry condition with large contact area

g) Skin impedance

Once the skin resistance and the skin capacitance are known, it is possible to estimate the skin impedance $Z_s(t)$, for a certain time of current flow, by using the following equation:

$$Z_{s-h-h}(t) = \frac{\left(\frac{1}{C_s}\right)}{\sqrt{(2f\pi)^2 + \left(\frac{1}{R_s(t) \cdot C_s}\right)^2}} \quad \text{B.VIII}$$

h) Skin voltage

From the skin impedance value, it is possible to estimate the voltage directly applied to the skin $V_s(t)$ (at the skin “terminals”). This voltage depends on the current flowing through the skin and which is for a hand-to-hand current path equal to the hand-to-hand current calculated in a)

$$V_s(t) = Z_s(t) \times I_{h-h} \quad \text{B.IX}$$

This value of $V_s(t)$ will be used for other current paths through the human body.

All these calculations need to be repeated for different values and combinations of the following parameters:

- touch voltage
- skin capacitance density
- skin conditions (dry, water-wet, saltwater-wet)
- time of current flow.

B.3.1.2 Hands-to-Feet path

a) Calculation of the internal resistance

For different current path, the resistance of internal tissue has a different value. The new value $R_{i\ h-f}$ for a current path from 2 hands to 2 feet can be estimated from the internal resistance corresponding to hand-to-hand current path ($R_{i\ h-h}$) by the following method.

All total impedance values provided by IEC 60479-1 correspond to hand-to-hand current path. Internal tissue through which current is flowing corresponds to the internal tissue of the two arms and the trunk when crossed transversely by the current.

The IEC 60479-1 also provides the possibility of finding internal resistance values corresponding to different current paths by using percentage of the internal resistance for a hand-to-hand current path.

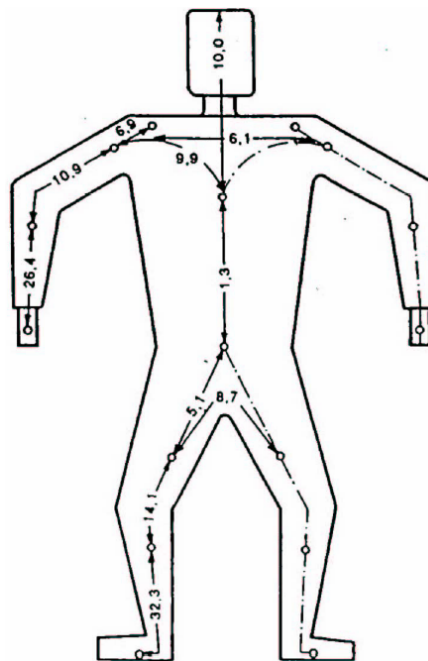


Figure B3: Percentage of the internal resistance of the human body for the part of the body concerned

- Percentage for hand to hand current path:

$$26.4\% + 10.9\% + 6.1\% + 10.9\% + 26.4\% = 80.7\%$$

- Percentage for two hand to two feet current path:

$$\frac{(26.4\% + 10.9\% + 9.9\%)}{2} + 1.3\% + \frac{(5.1\% + 14.1\% + 32.3\%)}{2} = 50.65\%$$

As the reference corresponds to hand to hand current path, for a both hands to both feet current path, the internal impedance value corresponds to: $\frac{50.65\%}{80.7\%} = 0.628$ times the internal resistance value for hand to hand current path.

It is possible to estimate the internal resistance $R_{i\ h-f}$ of the human body for both-hands to both-feet current path from the internal resistance $R_{i\ h-h}$ for a hand-to-hand current path, as follows:

$$R_{i\ h-f} = R_{i\ h-h} \times 0.628$$

b) Hands-to-Feet current

From the skin impedance value $Z_{s\ h-h}(t)$ calculated for the hand-to-hand current path and from the skin voltage $V_s(t)$ also calculated for the hand-to-hand current path, it is possible to calculate the corresponding value of the current flowing through the human body for the hands-to-feet current path I_{h-f} from the following formula:

$$I_{h-f} = 2 \times \frac{V_s(t)}{Z_{s\ h-h}(t)} \quad \text{B.X}$$

The coefficient 2 comes from the fact that the current through the torso is twice the current through one hand, because in this situation both hands are in contact with a live part are at the same voltage (see model described in figure A2 of Annex A).

c) Total impedance

It is now possible to estimate the new total impedance value for the human body by using the following formula:

$$Z_{h-f} = \frac{R_{i\ h-f} \times \sqrt{(2f\pi)^2 + \frac{(R_{i\ h-f} + R_s(t))^2}{(R_{i\ h-f} \times R_s(t)C_s)^2}}}{\sqrt{(2f\pi)^2 + \left(\frac{1}{R_s(t)C_s}\right)^2}} \quad \text{B.XI}$$

Obviously this new value of the hands-to-feet human body impedance does not correspond to the same touch voltage as calculated for a hand-to-hand current path. The new touch voltage values correspond to the estimated touch voltage for the hand-to-hand current path.

d) Touch voltage

The new touch voltage $V_{t\ h-f}$ can be estimated by the following way:

$$V_{t\ h-f} = Z_{h-f} \times I_{h-f}$$

Again, these calculations have to be done for each parameter here above mentioned.

B.3.1.3 Hand-to-Seat path

a) Calculation of the internal resistance

In a similar way as explained in B.3.1.2 a), it is possible to estimate the internal resistance of the human body for this particular current path from the internal resistance corresponding to the hand-to-hand current path.

Percentage for one hand to seat current path:

$$26,4\% + 10,9\% + 9,9\% + 1,3\% = 48,5\%$$

For a one hand-to-seat current path, the internal impedance value corresponds to: $\frac{48,5\%}{80,7\%} = 0,601$ times the internal resistance value corresponding to a hand-to-hand current path

Therefore, it is possible to estimate the internal resistance $R_{i\ h-f}$ of the human body for hand-to-seat current path from the internal resistance $R_{i\ h-h}$ for an hand-to-hand current path, as follows:

$$R_{i\ h-s} = R_{i\ h-h} \times 0,601$$

b) Total impedance

The method is similar to the one used for the hands-to-feet path, with some modifications.

The new value of the total human body impedance is given from the following formula:

$$Z_{h-s} = \frac{R_{i\ h-s} \times \sqrt{(2f\pi)^2 + \frac{(R_{i\ h-f} + R_s(t))^2}{(R_{i\ h-f} \times R_s(t)C_s)^2}}}{\sqrt{(2f\pi)^2 + \left(\frac{1}{R_s(t)C_s}\right)^2}} \quad \text{B.XII}$$

As for the hands-to-feet current path, this new value of the hand-to-seat impedance of the human body does not correspond to the same touch voltage as the one calculated for a hand-to-hand path.

c) Hand-to-seat current

From the skin impedance value $Z_{s\ h-h}(t)$ calculated for the hand-to-hand current path and from the skin voltage $V_s(t)$ also calculated for the hand-to-hand current path, it is possible to calculate the corresponding value of the current flowing through the human body for the hand-to-seat current path from the following formula:

$$I_{h-s} = \frac{V_s(t)}{Z_{s\ h-h}(t)} \quad \text{B.XIII}$$

In this situation, the current through the torso is equal to the current through the hand (see model described in figure A3 of Annex A)

d) Touch voltage

The new touch voltage $V_{t\ h-s}$ is estimated from the following way:

$$V_{t\,h-s} = Z_{h-s} \times I_{h-s}$$

B.XIV

New calculations have to be done for the different parameters here above mentioned.

B.3.2 Algorithms of calculation of voltage thresholds in a.c. current

B.3.2.1 Hand-to-Hand path

For each touch voltage $V_{t\,h-h}$, values for Z_{h-h} and I_{h-h} have been estimated. It is now possible to draw graphics representing currents through the human body as a function of the touch voltages V_{h-h} .

In addition values of the minimum thresholds corresponding to the physiological effects considered need to be superimposed. The thresholds, for the hand-to-hand current path, are:

Current threshold (mA)	0,01s	0,02s	0,06s	0,1s	0,2s	0,6s	1s	10s
Muscular reaction	200	135	73	55	37	20	15	5
Ventricular fibrillation	1250	1238	1175	1000	650	200	125	100

Table B3: maximum a.c. current threshold corresponding to current flow duration for each current effect considered and for a hand-to-hand current path

For a current duration of 200 ms, the body current line crosses the 37 mA muscular reaction (MR) current threshold curve at 35 V and the 650 mA ventricular fibrillation (VF) current threshold curve at 438 V (see figure C1).

The touch current is a function of the touch voltage and corresponds to the body impedance characteristic.

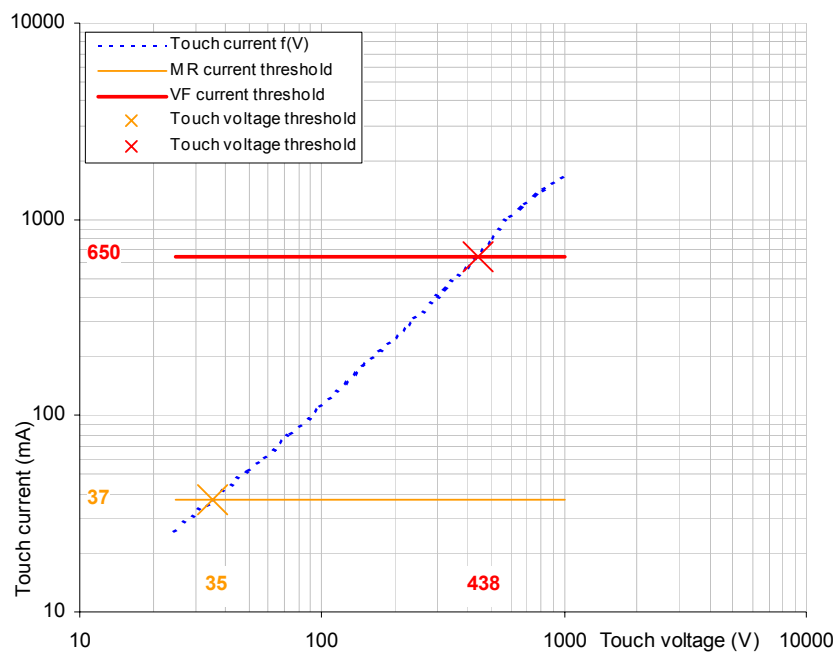


Figure B4: example of diagram for the estimation of the muscular reactions and ventricular fibrillation threshold for a.c. current hand-to-hand current path, large contact area and saltwater wet condition for a current duration of 200 ms

In this example, the curves plotted in log-log axis systems seem to be rectilinear. It may thus be adequate to calculate the values corresponding to the crosses of the curves by using logarithmic interpolation.

All these calculations here-above described have to be done for different values of the following parameters:

- Status of the skin (dry, water-wet, salt water-wet)
- Skin contact area (small, medium, large)
- Time for the current flow

B.3.2.2 Hands-to-Feet path

The similar method applies for this current path through the human body. Different values of minimum current thresholds will apply:

Current threshold (mA)	0,01s	0,02s	0,06s	0,1s	0,2s	0,6s	1s	10s
Muscular reaction	200	153	99	80	62	40	30	10
Ventricular fibrillation	500	495	470	400	260	80	50	40

Table B4: maximum a.c. current threshold corresponding to current flow duration for each current effect considered for the hands-to-feet current path

Here again, calculations have to be done for all here above described parameters.

B.3.2.3 Hand-to-Seat path

Here again the same method applies as previously used with the following minimum current threshold values

Current threshold (mA)	0,01s	0,02s	0,06s	0,1s	0,2s	0,6s	1s	10s
Muscular reaction	200	135	73	55	37	20	15	5
Ventricular fibrillation	714	707	671	571	371	114	71	57

Table B5: maximum a.c. current threshold corresponding to current flow duration for each current effect considered for the hand-to-seat current path

Here again, calculations have to be done for all here above described parameters.

B.3.2.4 Diagram time/Voltage

Once all these calculations here above described have been done, then it is possible to draw voltage/time diagrams by gathering the values corresponding to similar application (current path, skin condition, and skin contact area) but for increasing duration's of current flow.

Some simplifications are needed:

All calculations have performed for 3 values of the skin capacitance density (low, medium and high) (see B.2.2.1). For reasons of safety of persons it is possible to select the value of the capacity resulting in the minimum voltage threshold.

With this simplifying hypothesis, it is now possible to draw the curves of voltage/time thresholds corresponding to the time/current thresholds of IEC 60479-1. All figures are provided in Annex C.

B.3.3 Algorithms of calculation of the impedance in d.c. current

Calculations in d.c. current are simpler than in a.c. current because it is possible to neglect the influence of the skin capacitances. The method used is similar to the one used for a.c. current.

B.3.3.1 Hand-to-Hand path

a) Hand-to-hand current

The IEC 60479-1 provides values for the resistance of the human body R_{h-h} for a hand-to-hand path and for each touch voltage V_{th-h} (hand-to-hand)

The hand-to-hand current I_{h-h} is given by:

$$I_{h-h} = \frac{V_{th-h}}{Z_{h-h}} \quad \text{B.XV}$$

b) Internal resistance

As in a.c. current, the internal resistance R_{ih-h} corresponds to the asymptotic value of the hand-to-hand impedance curve as a function of the touch voltage. In fact the same physiological effects appear in d.c. current.

$$R_{ih-h} = Z_{h-h}(1000) \quad \text{B.XVI}$$

c) Skin resistance

The human body resistance is equal to the sum of the two skin resistances of both hands and of the internal tissue resistance. Therefore it is now possible to estimate the skin resistance of one single hand from the following formula:

$$R_s = \frac{Z_{h-h} - R_{ih-h}}{2} \quad \text{B.XVII}$$

d) Readjustment of the skin resistance

In the same way as for a.c. current, the skin resistance requires a fraction of second to be tuned correctly to its final value depending on the voltage, which is directly applied to it. The skin resistance $R_s(t)$ at a given time t is estimated by using the following formula:

$$R_s(t) = R_s + (R_s(0) - R_s) e^{-t/0,05} \quad \text{B.XVIII}$$

in which $R_s(0)$ corresponds to the initial value of R_s when the skin voltage was zero.

e) Estimation of the initial skin resistance

This estimation is possible by linear extrapolation of the curve giving R_{h-h} function of V_t for value of V_t equal to 0 volt.

From this initial value of the hand-to-hand resistance $R_{h-h}(0)$, a calculation similar to c) and d) is possible in order to determine the initial value of the skin resistance $R_s(0)$.

f) Skin voltage

Here again it is now possible to calculate the voltage directly applied to the skin V_s . This voltage is estimated in the same way as in a.c. current.

$$V_s = R_s(t) \times I_{h-h} \quad \text{B.IXX}$$

Here also this value of V_s will be used for other current paths through the human body.

All these calculations here above described have to be done for different values of the following parameters:

- Touch voltage
- Skin condition (dry; water-wet, salt water-wet)
- Contact area (small, medium, large)
- Current flow duration

B.3.3.2 Hands-to-Feet path

a) Calculation of the internal resistance

For a different path the internal impedance which is estimated to be a resistance is different. The correcting factor applied for a.c. current is applicable for the d.c. current.

$$R_{i h-f} = R_{i h-h} \times 0,628$$

b) Hands-to-Feet current

The hands-to-Feet current is determined in a similar way as for the a.c. current.

$$I_{h-f} = 2 \times \frac{V_s}{Z_{h-h}} \quad \text{B.XX}$$

The same coefficient of 2 also applies.

c) Total impedance

The estimation of the total resistance is here much simpler than in a.c. current because phase angles due to the presence of skin capacitances has not to be taken into consideration. The following formula applies:

$$R_{m-p} = 2 \times R_p(t) + R_{im-p} \quad \text{B.XXI}$$

d) Touch contact

The new touch voltage $V_{c\ m-p}$ is obtained in the following way:

B.XXII

$$V_{c\ m-p} = R_{m-p} \times I_{m-p}$$

Still, these calculations need to be done for the different parameters here above mentioned.

B.3.3.3 Hand-to-Seat path

a) Calculation of the internal resistance

As for the hands-to-feet current path, which differs from the hand-to-hand current path, which is our reference of calculation, the internal resistance is different. The same correcting factor used in a.c. current is also applicable here in d.c.

$$R_{i\ h-s} = R_{i\ h-h} \times 0,601$$

b) Hand-to-Seat current

The hand-to-seat current is now estimable by the following formula:

B.XXIII

$$I_{h-s} = \frac{V_s}{Z_{h-h}}$$

We have to remind that in this situation the current through the torso is equal to the current through the hand.

c) Total resistance

The new value of the total resistance of the human body is simply the algebraic sum of the skin resistance and of the internal resistance:

B.XXIV

$$R_{h-s} = R_{i\ h-s} + R_s(t)$$

d) Touch voltage

The new touch voltage $V_{t\ h-s}$ is obtained in the following way:

B.XXV

$$V_{t\ h-s} = R_{h-s} \times I_{h-s}$$

Still these calculations have to be done for the different parameters here above described.

B.3.4 Algorithms of calculation of the voltage thresholds in d.c. current

B.3.4.1 Hand-to-Hand path

In the same way as for a.c. current, we have estimated the values of R_{h-h} and of I_{h-h} for each value of V_{h-h} . It is now possible to draw the graphic giving the current through the human body I_{h-h} as a function of the touch voltages V_{h-h} .

If we superimpose on these graphics the values of the current thresholds for the desired physiological effects, we are now able to estimate the values of the voltage thresholds by calculating the abscissa of the crossing points of these curves.

The values for the minimum thresholds in current for this current path are:

Current threshold (mA)	0,01s	0,02s	0,06s	0,1s	0,2s	0,6s	1s	10s
Muscular reaction	200	153	99	81	62	40	33	25
Ventricular fibrillation	1250	1238	1175	1000	650	400	375	350

Table B6: maximum d.c. current threshold corresponding to current flow duration for each current effect considered for the hand-to-hand current path

In this example, curved plotted in a log-log scale seem to be rectilinear. It may appear opportune to calculate the values at crossing of curves by logarithmic interpolation. Nevertheless the curves are not always rectilinear in this log-log axis system, this is why it has appeared wise to use both types of know interpolations (see 4.2.4).

All these described calculations need to be done for the values of the following parameters:

- Skin condition (dry, water-wet, salt water-wet)
- Contact area (small, medium, large)
- Population percentile
- Current flow duration

B.3.4.2 Hands-to-feet path

The same method applies for this current path through the human body. Different values for the minimum current thresholds have to be used:

Current threshold (mA)	0,01s	0,02s	0,06s	0,1s	0,2s	0,6s	1s	10s
Muscular reaction	200	153	99	81	62	40	33	25
Ventricular fibrillation	500	495	470	400	260	160	150	140

Table B7: maximum d.c. current threshold corresponding to current flow duration for each current effect considered for the hands-to-feet current path

Once again the same calculation have to be done for all parameter here above listed.

B.3.4.3 Hand-to-Seat path

Once again methods similar to the ones used previously apply with minimum threshold values in current as follows:

Current threshold (mA)	0,01s	0,02s	0,06s	0,1s	0,2s	0,6s	1s	10s
Muscular reaction	200	153	99	81	62	40	33	25
Ventricular fibrillation	714	707	671	571	371	229	214	200

Table B8: maximum d.c. current threshold corresponding to current flow duration for each current effect considered for the hand-to-seat current path

Once again the same calculation have to be done for all parameter here above listed.

B.3.4.4 Time/Voltage diagrams

As for the a.c. current, it is now possible to draw the time/voltage diagrams by gathering the values corresponding to the same applications (current path, skin condition, contact area) but for the increasing current flow duration's.

Some simplification is here needed for d.c. current concerning the selection among 2 types of interpolations. As for a.c. current, and for favouring the safety of persons, the selection will be done on the type of interpolation providing the smallest voltage threshold.

With this simplifying hypothesis, it is now possible to draw the curves of the time/voltage zones corresponding to the time/current zones of the IEC 60479-1. All figures are provided in Annex C

Annex C

Touch voltage thresholds – presentation of the voltage-time curves

(normative)

Based on the human body impedances and on the current – time curves as provided in IEC 60479-1, the following set of diagrams provide the maximum time acceptable for a given touch voltage applied to a human body. These curves have been established by using the method as described in Annex B with the model as described in Annex A.

For each type of current (alternating current and direct current) there are nine diagrams corresponding to the followings parameters:

- skin conditions (dry, waterwet and salt-waterwet); and
- contact area (large, medium and small).

Each diagram includes a set of six curves corresponding to :

- the three different current paths through the human body considered in this document (Hand-to-Hand; Hands-to-Feet and Hand-to-Seat), and to
- The two different current thresholds considered in this document (Muscular reaction and ventricular fibrillation).

These curves shall be used as a guide by IEC Technical Committees when prescribing the maximum disconnecting time of the protective device used for the automatic disconnection of supply. For example, the following characteristics need to be considered and might make adjustments appropriate in the process of selecting limits:

- the symmetrical restriction of the electrical model resulting from the inability of the model to handle more than one electrical operating point of the nonlinear nature of the skin at a time.
- the limited number of discrete levels of contact area, moisture of contact, and body current pathway that are assumed.
- the limited number of only two physiological thresholds resulting from electric current (direct muscular effects including inability to let go, and ventricular fibrillation).

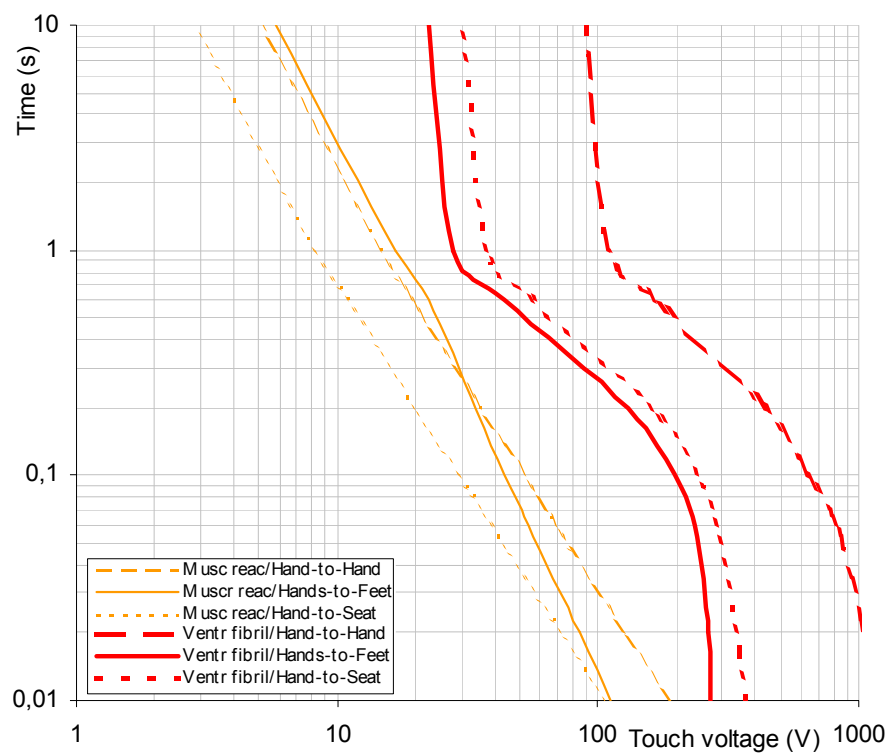


Fig C1: Conventional time/voltage zones of effects of a.c. current (50/60 Hz) on person for saltwater wet condition and large contact area

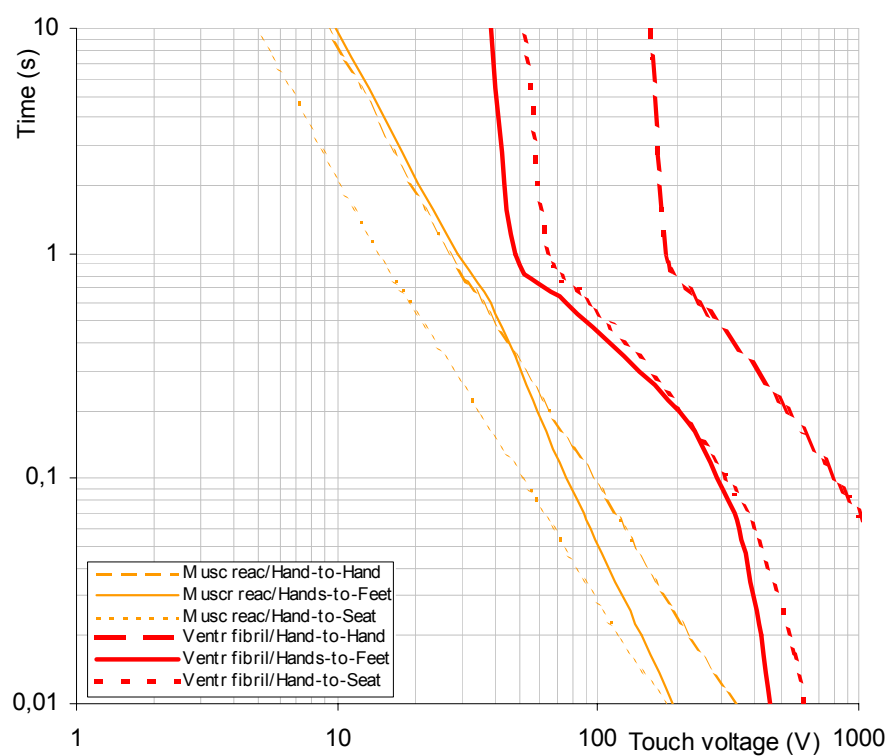


Fig C2: Conventional time/voltage zones of effects of a.c. current (50/60 Hz) on person for saltwater wet condition and medium contact area

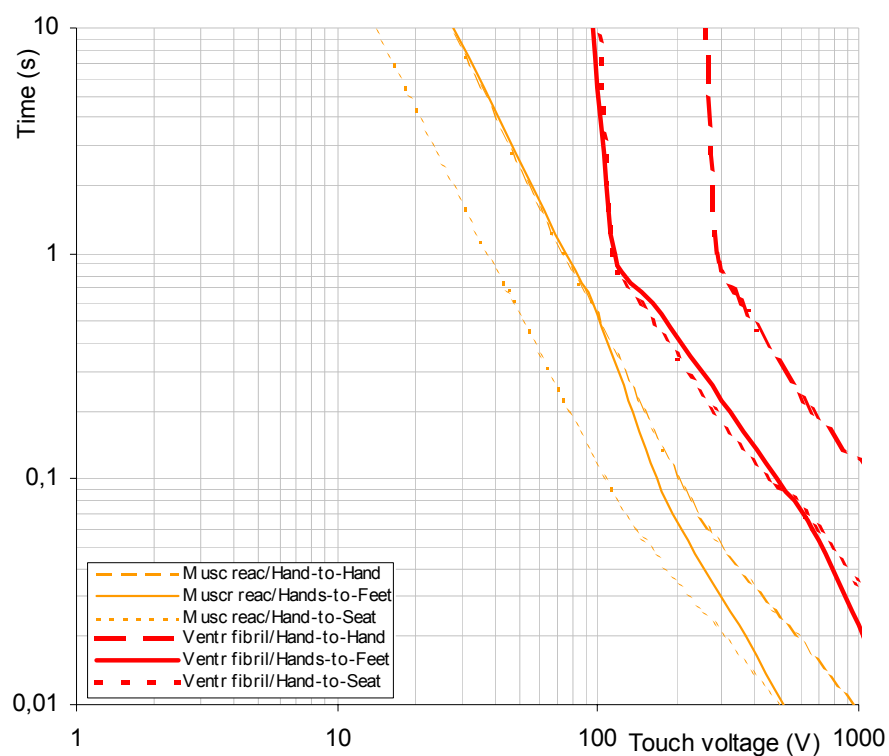


Fig C3: Conventional time/voltage zones of effects of a.c. current (50/60 Hz) on person for saltwater wet condition and small contact area

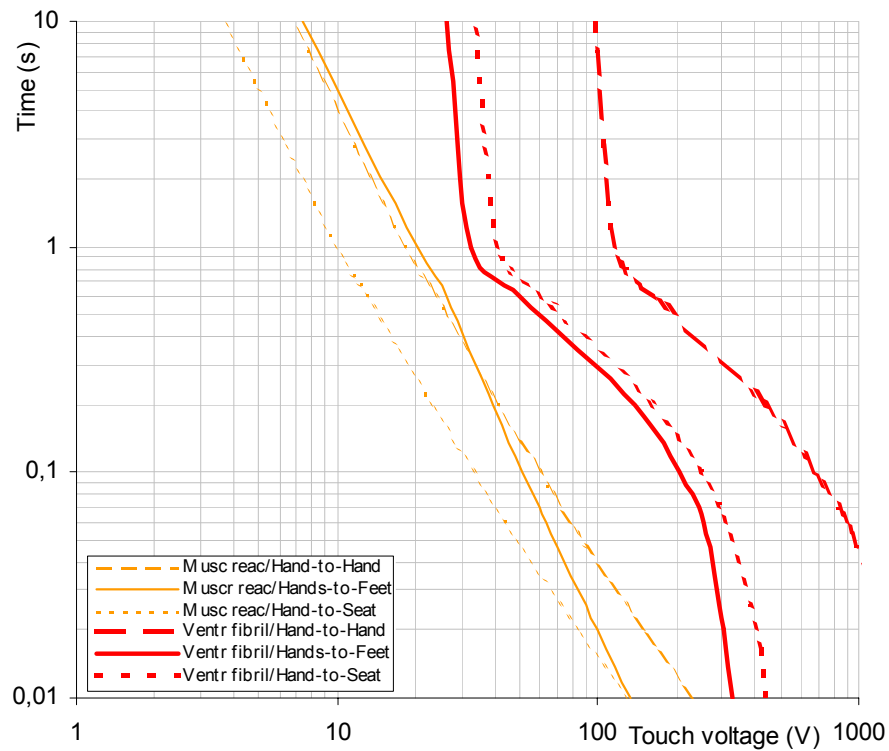


Fig C4: Conventional time/voltage zones of effects of a.c. current (50/60 Hz) on person for water wet condition and large contact area

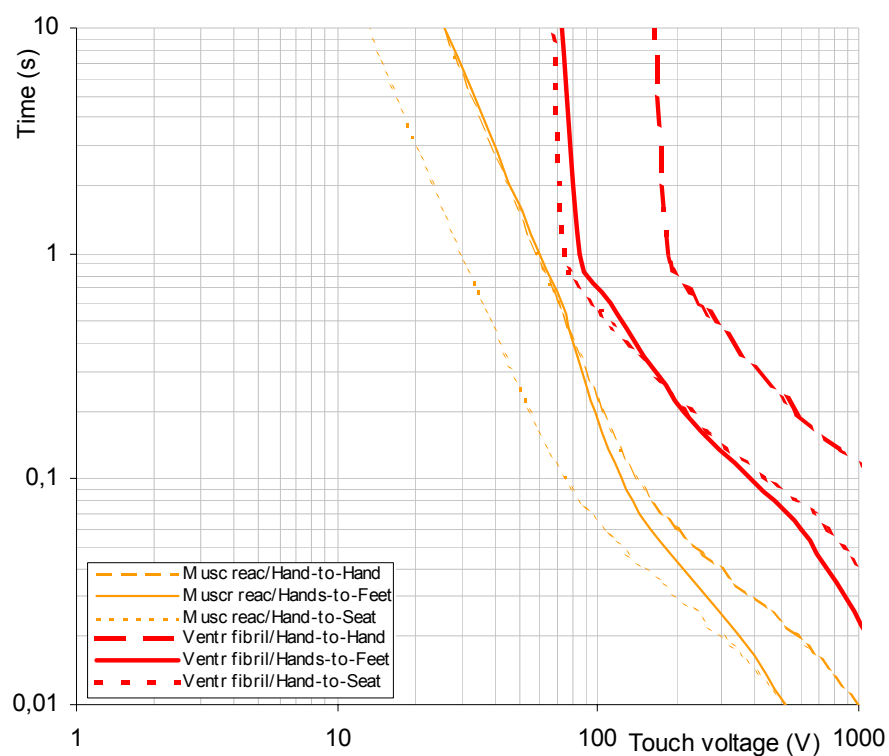


Fig C5: Conventional time/voltage zones of effects of a.c. current (50/60 Hz) on person for water wet condition and medium contact area

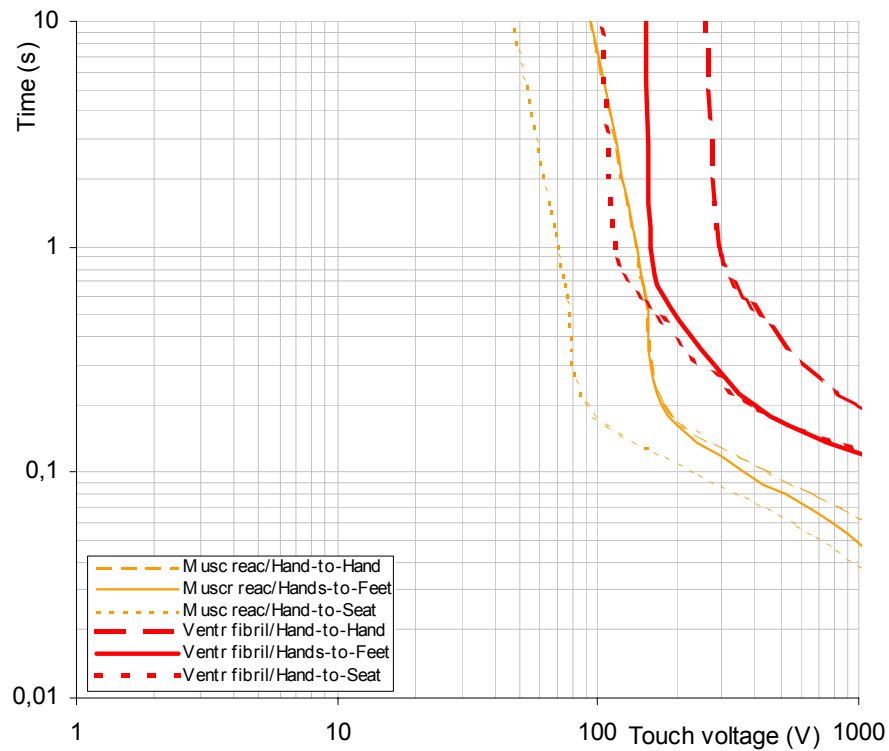


Fig C6: Conventional time/voltage zones of effects of a.c. current (50/60 Hz) on person for water wet condition and small contact area

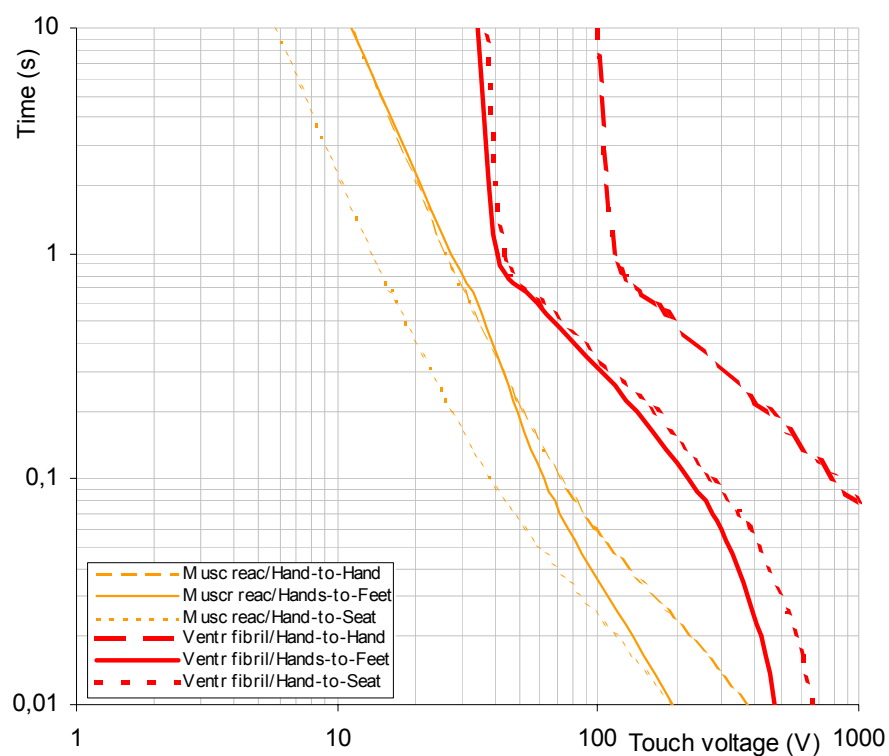


Fig C7: Conventional time/voltage zones of effects of a.c. current (50/60 Hz) on person for dry condition and large contact area

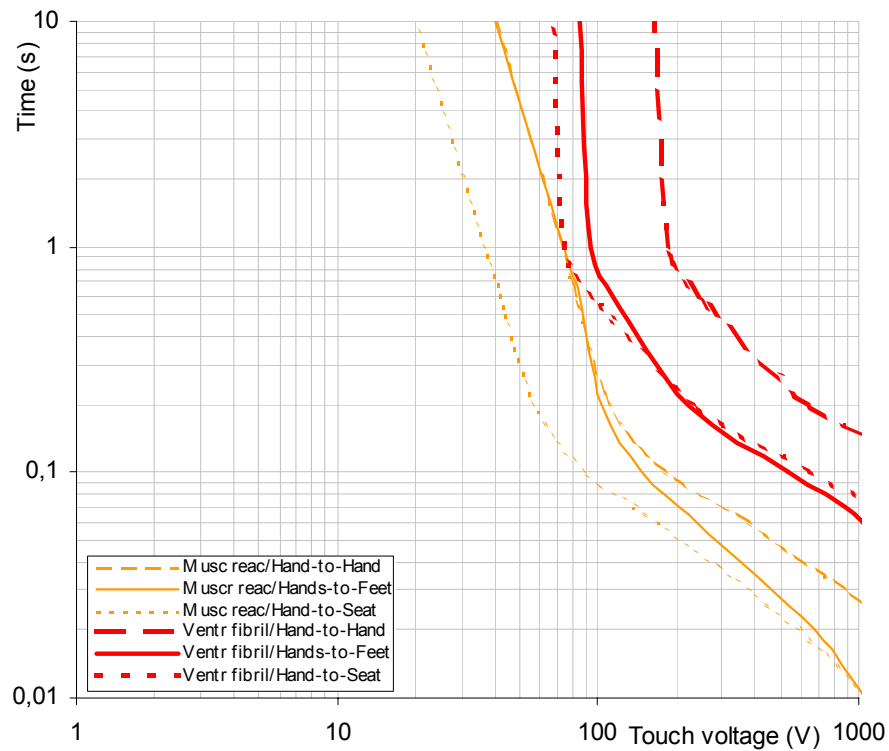


Fig C8: Conventional time/voltage zones of effects of a.c. current (50/60 Hz) on person for dry condition and medium contact area

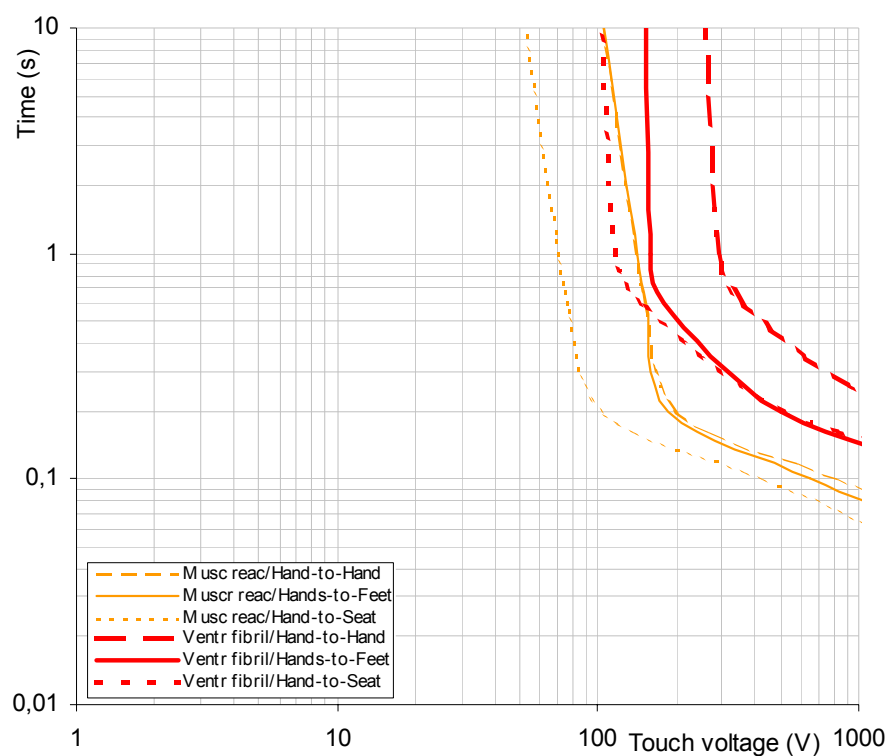


Fig C9: Conventional time/voltage zones of effects of a.c. current (50/60 Hz) on person for dry condition and small contact area

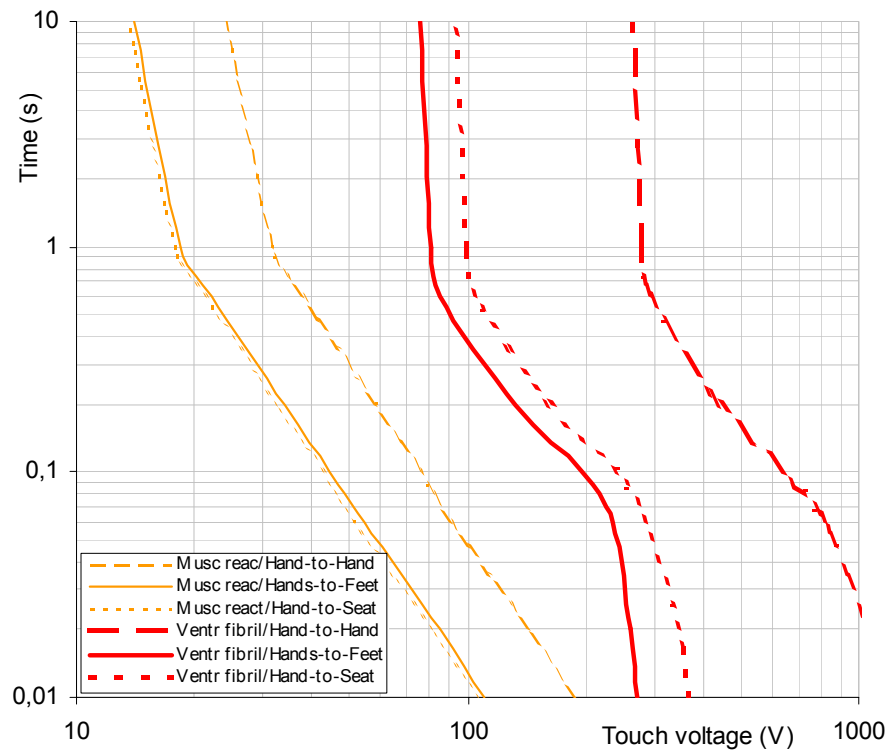


Fig C10: Conventional time/voltage zones of effects of d.c. current on person for saltwater wet condition and large contact area

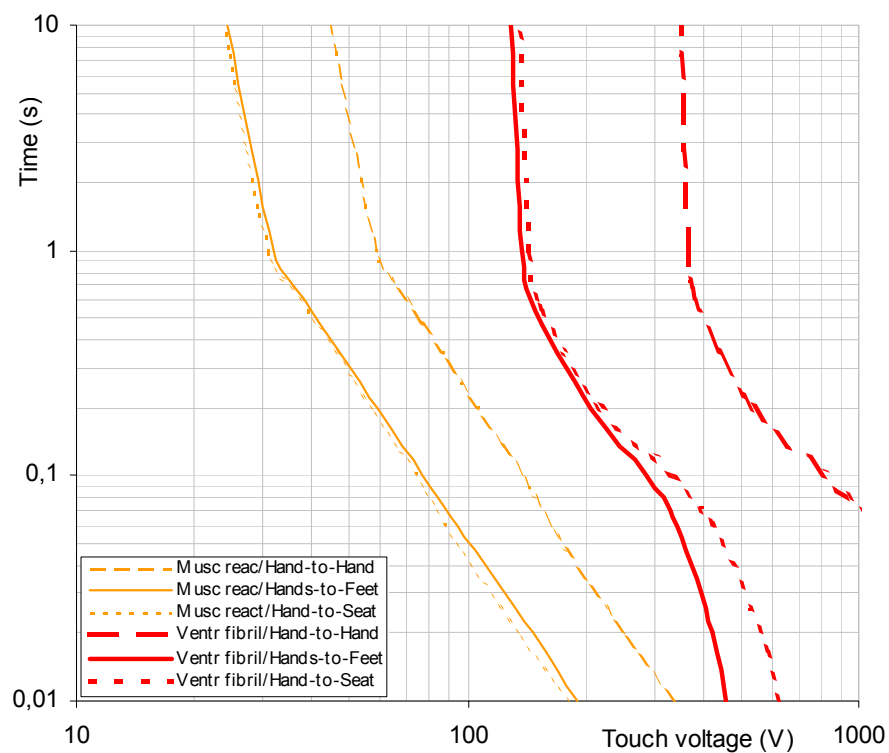


Fig C11: Conventional time/voltage zones of effects of d.c. current on person for saltwater wet condition and medium contact area

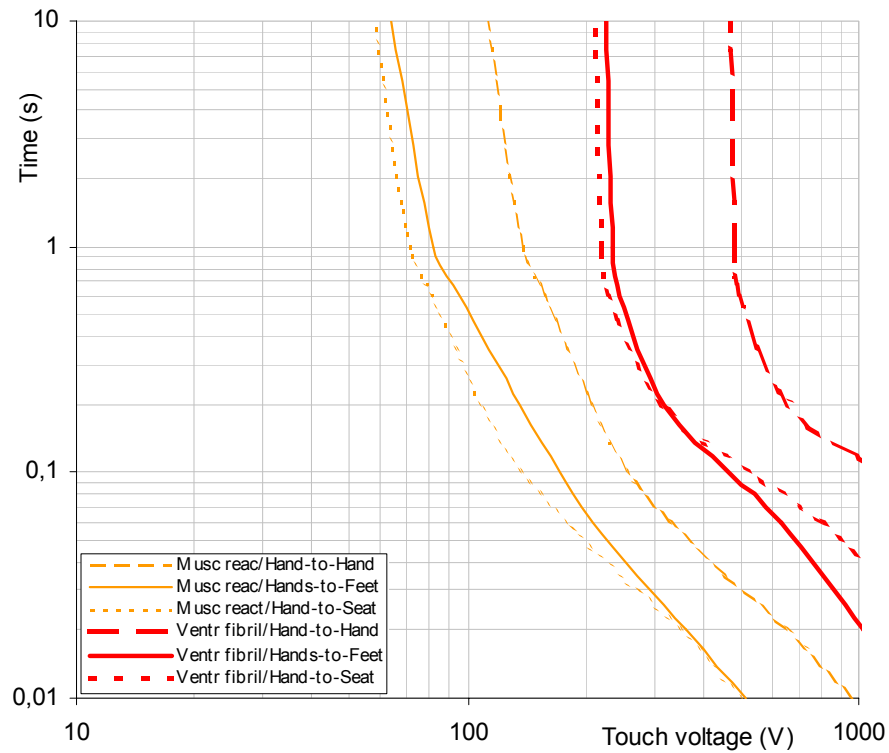


Fig C12: Conventional time/voltage zones of effects of d.c. current on person for saltwater wet condition and small contact area

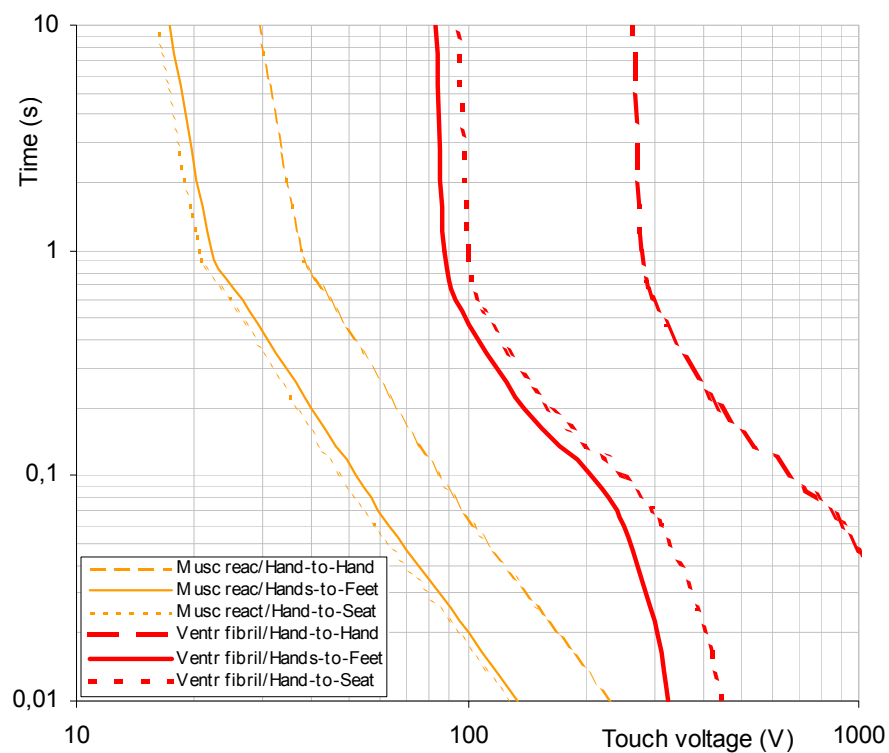


Fig C13: Conventional time/voltage zones of effects of d.c. current on person for water wet condition and large contact area

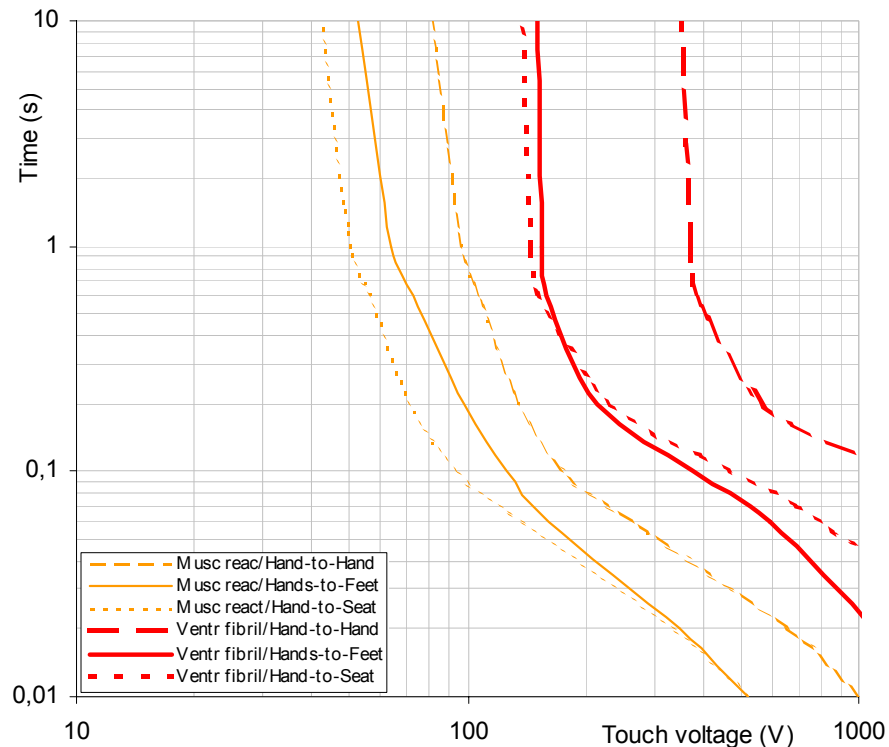


Fig C14: Conventional time/voltage zones of effects of d.c. current on person for water wet condition and medium contact area

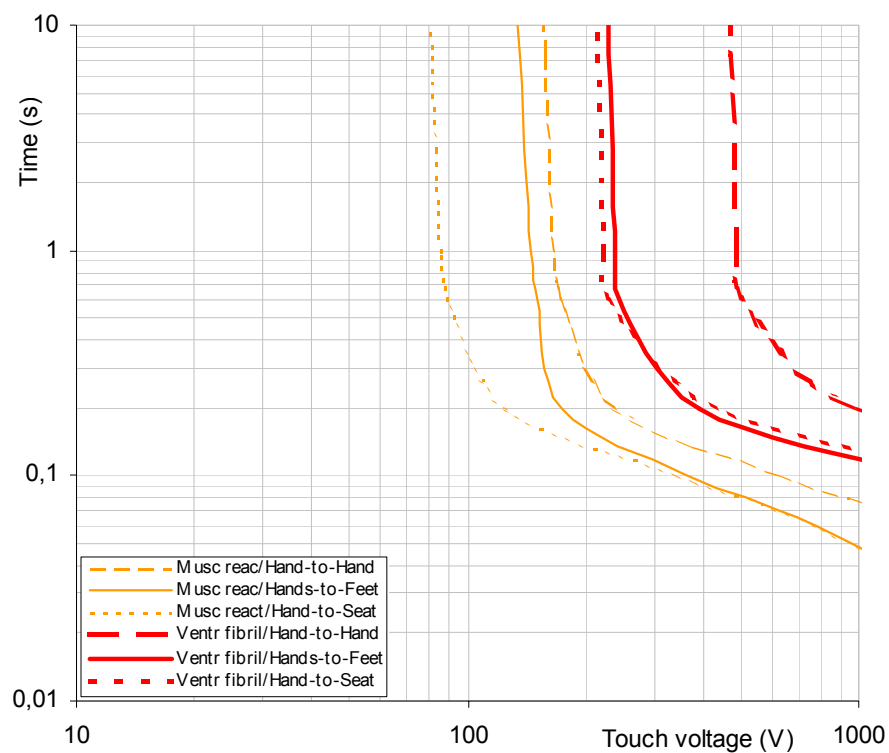


Fig C15: Conventional time/voltage zones of effects of d.c. current on person for water wet condition and small contact area

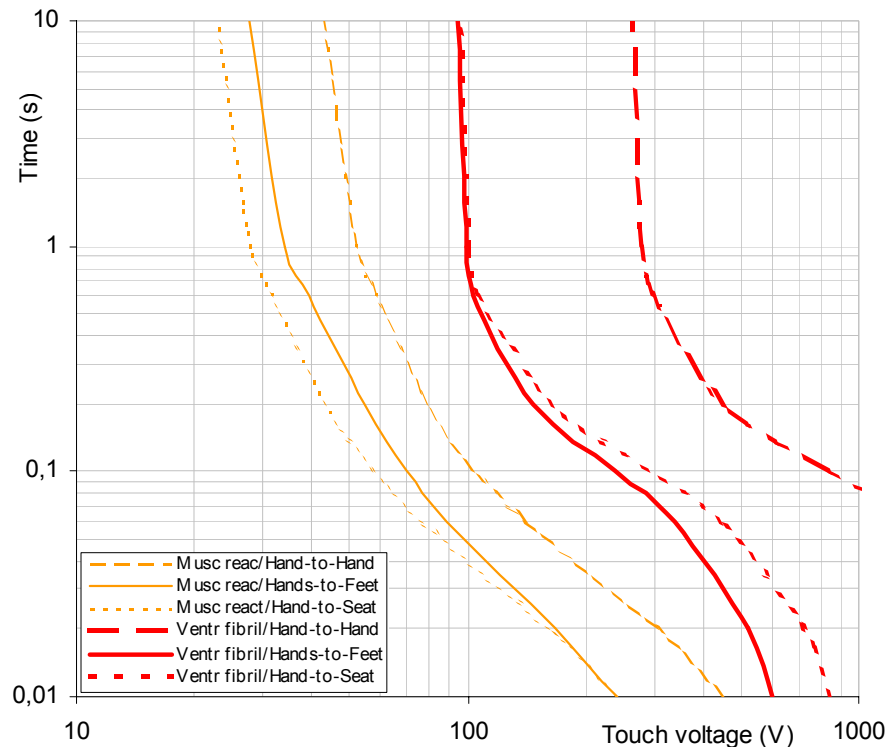


Fig C16: Conventional time/voltage zones of effects of d.c. current on person for dry condition and large contact area

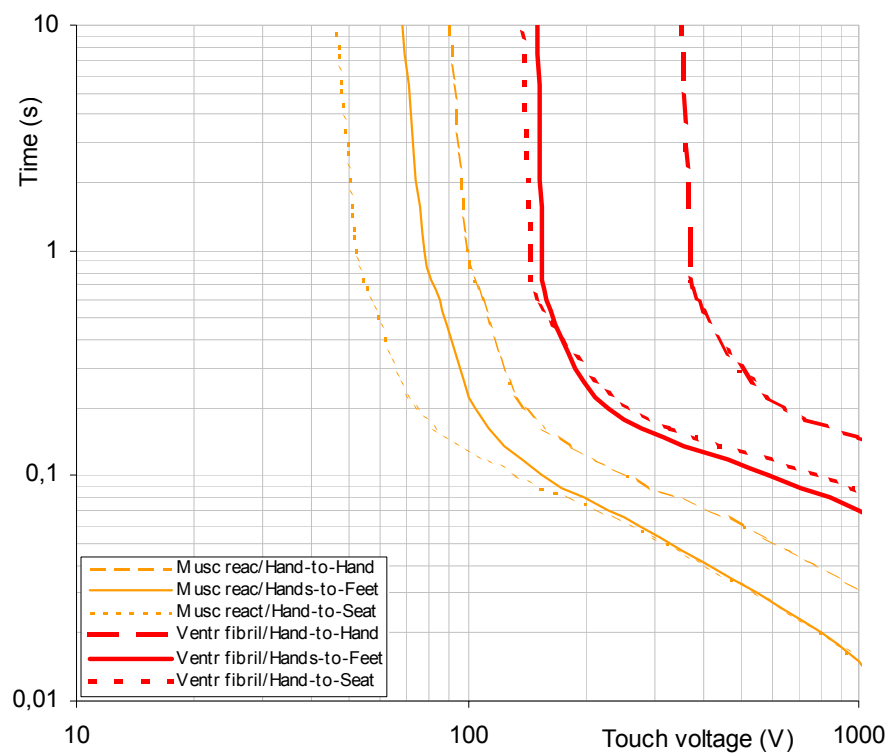


Fig C17: Conventional time/voltage zones of effects of d.c. current on person for dry condition and medium contact area

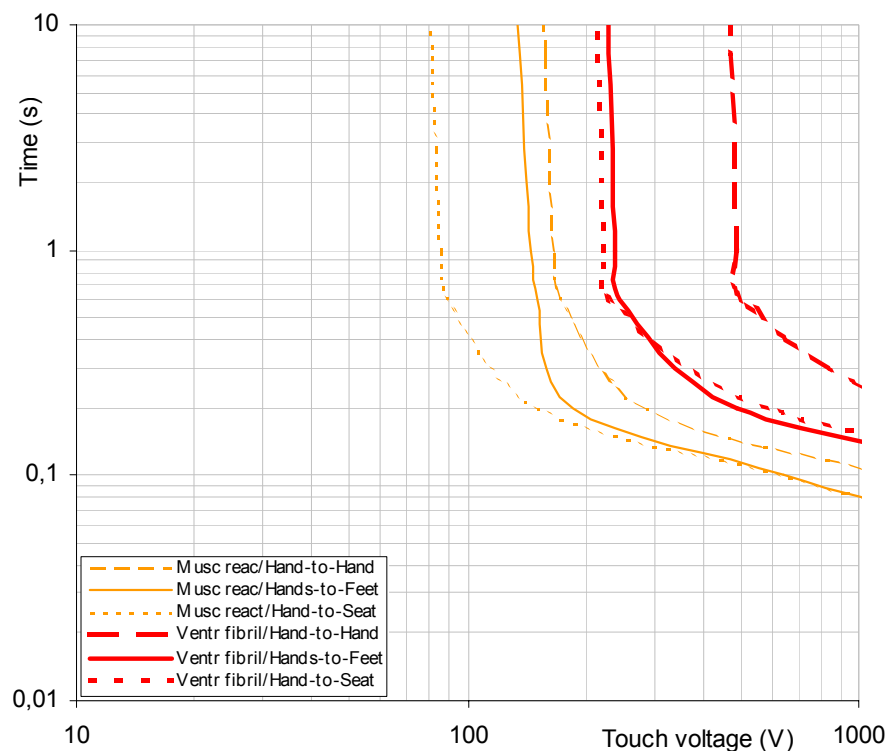


Fig C18: Conventional time/voltage zones of effects of d.c. current on person for dry condition and small contact area

Annex D

Examples of maximum contact areas for specified conditions

(informative)

D.1 Comparison with traditional voltage limits

Traditional voltage limits based on these thresholds (for example 50 V a.c. or 120 d.c.) are generally acceptable in practice because external factors have reduced the risk such as:

- small contact area (finger rather than full hand contact)
- additional resistance in series (any clothing)
- non conductive accessible surfaces.

The table D1 illustrates maximum contact areas corresponding to given touch voltages that in turn relate to commonly used voltage limits. Safety factors should be applied in the selection of limits by users of this document leading to smaller maximum allowable contact areas.

Touch voltage	Moisture condition	Pathway of body current	Max contact area for touch voltage threshold * for muscular reaction	Max contact area for touch voltage threshold * for ventricular fibrillation
15 V ac rms	Water wet	hand-to-hand hands-to-feet hand-to-seat	26 cm ² 26 cm ² 9 cm ²	>100 cm ² >100 cm ² >100 cm ²
15 V ac rms	Saltwater wet	hand-to-hand hands-to-feet hand-to-seat	4 cm ² 4 cm ² 1 cm ²	>100 cm ² >100 cm ² >100 cm ²
25 V ac rms	Water wet	hand-to-hand hands-to-feet hand-to-seat	12 cm ² 12 cm ² 3 cm ²	>100 cm ² 90 cm ² >100 cm ²
25 V ac rms	Saltwater wet	hand-to-hand hands-to-feet hand-to-seat	1 cm ² 1 cm ² <1 cm ²	>100 cm ² 50 cm ² >100 cm ²
30 V ac rms	Dry	hand-to-hand hands-to-feet hand-to-seat	20 cm ² 20 cm ² 5 cm ²	>100 cm ² >100 cm ² >100 cm ²
50 V ac rms	Dry	hand-to-hand hands-to-feet hand-to-seat	7 cm ² 7 cm ² 1 cm ²	>100 cm ² 40 cm ² 33 cm ²

Table D1: Examples of maximum contact areas corresponding to given a.c. touch voltages

30 V dc	Water wet	hand-to-hand hands-to-feet hand-to-seat	75 cm ² 33 cm ² 23 cm ²	>100 cm ² >100 cm ² >100 cm ²
30 V dc	Saltwater wet	hand-to-hand hands-to-feet hand-to-seat	40 cm ² 7 cm ² 5 cm ²	>100 cm ² >100 cm ² >100 cm ²
60 V dc	Dry	hand-to-hand hands-to-feet hand-to-seat	40 cm ² 15 cm ² 3 cm ²	>100 cm ² >100 cm ² >100 cm ²
60 V dc	Water wet	hand-to-hand hands-to-feet hand-to-seat	23 cm ² 9 cm ² 3 cm ²	>100 cm ² >100 cm ² >100 cm ²
60 V dc	saltwater wet	hand-to-hand hands-to-feet hand-to-seat	5 cm ² 1 cm ² 1 cm ²	>100 cm ² >100 cm ² >100 cm ²
120 V dc	dry	hand-to-hand hands-to-feet hand-to-seat	<1 cm ² <1 cm ² <1 cm ²	>100 cm ² 30 cm ² 25 cm ²

* Note – The maximum tolerable contact area is for each contact with conductive surfaces. For hand-to-hand, the area is per hand. For hands-to-feet, the area is per hand and per foot. For hand-to-seat, the area is the hand contact alone. The seat contact is assumed to be very large, independent of the hand contact.

Table D2: Examples of maximum contact areas corresponding to given d.c. touch voltages

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